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JOINT TEST AND EVALUATION SUMMARY OF GREENLAND, ICELAND (DYE 4 - DYE 5) TROPOSCATTER RADIO LINK

Frank P. Chiffy
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JOINT TEST AND EVALUATION SUMMARY OF GREENLAND, ICELAND (DYE 4 - DYE 5) TROPOSCATTER RADIO LINK

Frank P. Chiffy
Italo A. Fantera

FOREWORD

Tests and evaluation discussed in this report were accomplished under Project 689A.

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This technical report has been reviewed and is approved.

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ABSTRACT

During the period of November 1967 to June 1968, tests were conducted on the DYE 4/5 Troposcatter Communications Link by Bell Telephone Laboratories (BTL), Communications & Systems Inc. (C&S), and Raytheon Company. The purpose of these tests was to evaluate techniques such as angle diversity, predetection diversity combining, and adaptive FM as possible means of improving the operational performance of that link. BTL's techniques consisted of angle diversity and a predetection combiner called "FALC"; C&S's technique was that of adaptive FM; and Raytheon's technique was a predetection combiner called "PDC."

This report describes the joint tests and the evaluation which was performed by RADC during March and April 1968 when the above-mentioned techniques were integrated into a single entity and compared to the normal-operational FM/FDM system.

Test results indicated that although both the test system and the normal-operational FM/FDM system performed rather poorly, the better performance was achieved most of the time by the operational FM/FDM system. There were also instances when propagation outage conditions occurred in the operational FM/FDM system but not in the test system. During such periods, the improved performance of the test system was attributed to its angle diversity aspects rather than to its predetection combining or adaptive FM aspects. It was also shown that the adaptive FM technique degrades the test system when the system also includes the FALC predetection combiner.

Recommendations include the use of angle diversity mainly to reduce propagation outages experienced if the system operation was limited to the boresight beams.

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SECTION I

INTRODUCTION

During the period October 1967 to June 1968, testing was conducted on the DYE 4/5 Troposcatter Communication Link to determine if the FM/FDM performance of the link could be substantially improved by employing techniques such as angle diversity, pre-detection diversity combining, and adaptive control of the FM characteristics.

The angle diversity (AD) and the pre-detection combining evaluation were performed by Bell Telephone Laboratories (BTL). These two concepts were evaluated separately, as well as jointly against the conventional FM/FDM system, and the results published in the final BTL report "Feasibility Trial of the Forward Acting Linear Combiner and Angle Diversity Reception on the DYE 4 - DYE 5 Troposcatter Radio Link", dated 1 November 1968. (As indicated by the report title, angle diversity was employed on a reception basis and "Forward Acting Linear Combiner" (FALC) refers to that specific combiner developed by BTL.)

The adaptive FM evaluation was performed by Communications & Systems, Inc., (CSI). This performance was also compared to that of the conventional FM system and the results published in the CSI report "Adaptive Noise Minimization" dated February 1969. The equipment which performs the adaptive control is referred to as "Adaptive Modulation Index" (AMI).

During March and April 1968, tests were conducted with the AD, FALC, and AMI integrated into a single entity (AD-FALC-AMI) and evaluated against the conventional FM/FDM system. This report is concerned not only with the relative performance of these two systems, but also with results which were observed regarding all operations during the March - April time interval.

1. TEST CONDITIONS

Because the DYE 4/5 Troposcatter Communication Link is an integral part of the North Atlantic Radio System (NARS) trunk line which carries vital communications traffic, it was imperative that any testing be done without interfering in any way with the normal operation or performance of the over-all system. The DYE 4/5 link performs at best only sub-marginally, so this meant that parameters such as transmission power, channel capacity, loading, etc., could not be significantly compromised.

2. AD-FALC VS CONVENTIONAL FM SYSTEM TEST CONFIGURATION

The test configuration used by BTL to compare the joint AD-FALC system with the conventional FM system is shown in Figure 1. The equipments representing the tested techniques are shown bridged into the appropriate points of the conventional receiving system at DYE 5. In addition, by hybriding a three-voice-channel multiplex/demultiplex test set with the transmitting/receiving terminals of the conventional FM system and a second such demultiplex test set and other terminal equipment at the output of the AD-FALC system, a non-interfering method was established to simultaneously compare the performances of the AD-FALC system and the conventional FM system.

3. AMI VS CONVENTIONAL FM SYSTEM TEST CONFIGURATION

The test configuration used by CSI to evaluate the AMI system against the conventional FM system is shown in Figure 2. The AMI technique adapts the transmitted FM wave to the variations of the path intermodulation noise, which means an automatic and continuous adjustment of the FM characteristics. Unlike the AD-FALC vs. conventional system evaluation, the AMI system cannot be evaluated simultaneously against the conventional FM system because the transmissions over this circuit at any given time cannot simultaneously be conventional FM and Adaptive FM. Consequently, CSI selected a comparison technique operating the AMI only during alternate test periods. This provided the basis for a statistical exan ination of the AMI system performance relative to that of the conventional FM system.

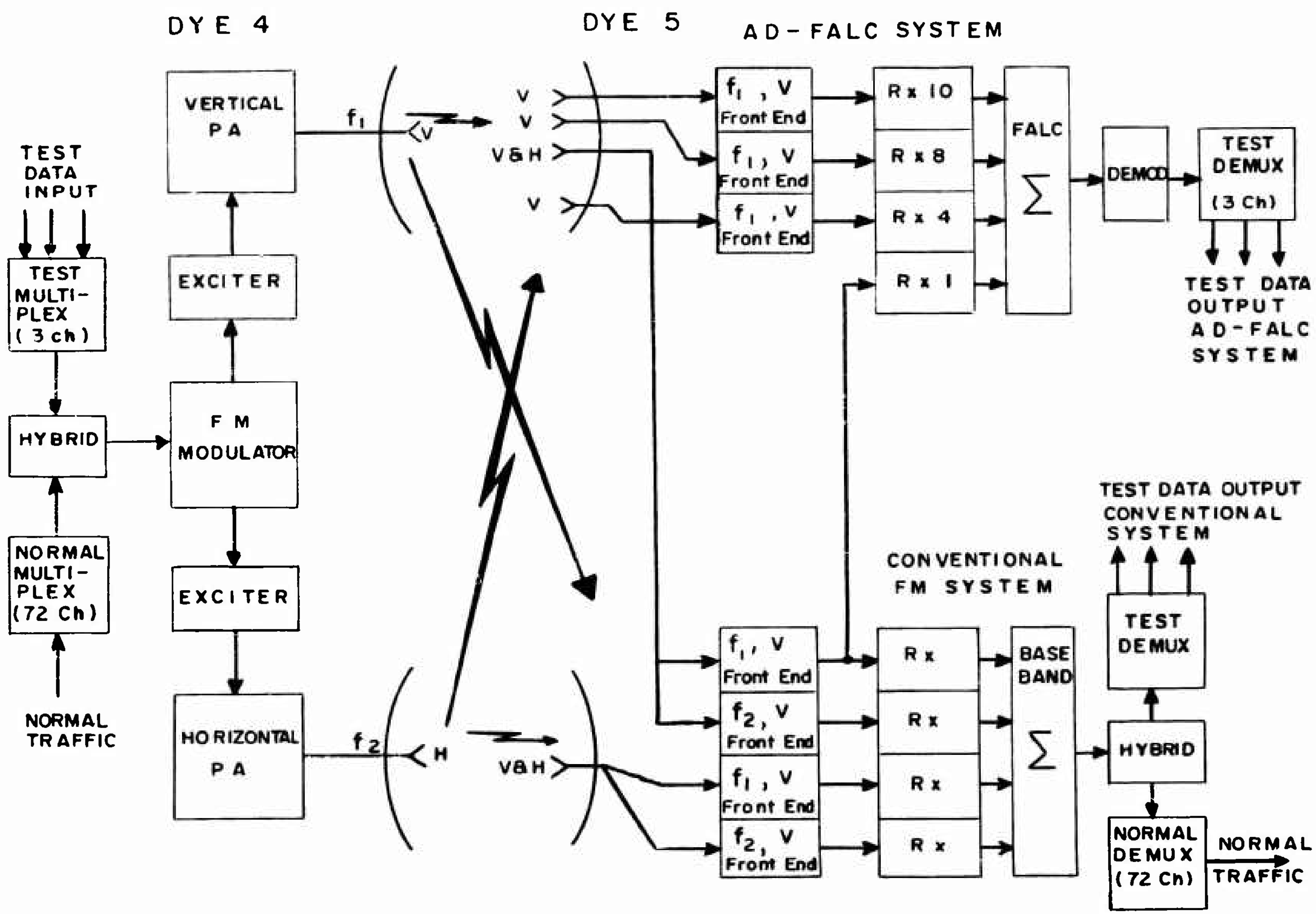

Figure 1. ADC-FALC vs. Conventional FM Configuration

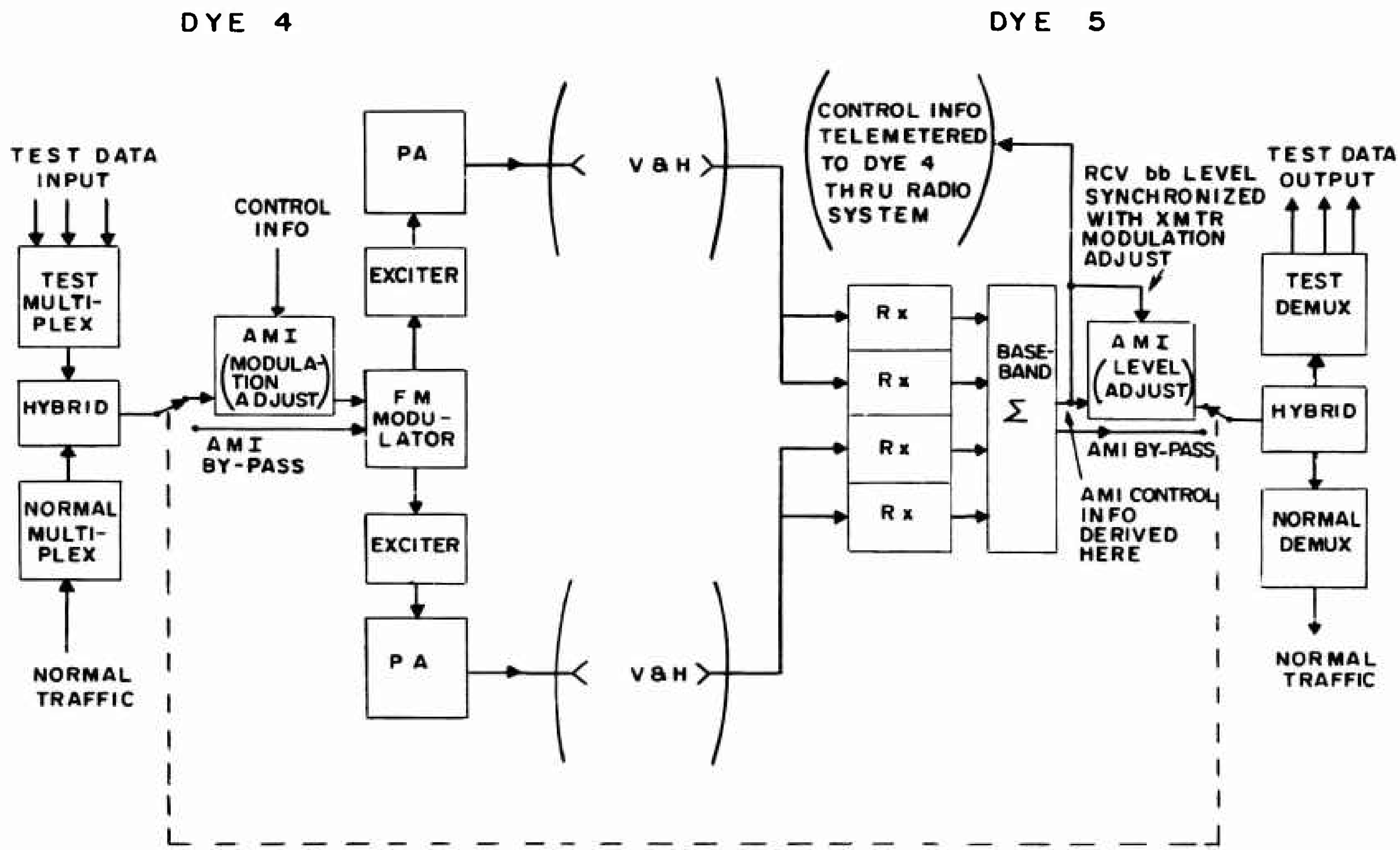

Figure 2. Adaptive FM vs. Conventional FM Configuration

SECTION II

AD-FALC-AMI TESTING

This section is concerned with those tests performed during March and April 1968. As previously indicated, the purpose was to compare the performances of the AD-FALC-AMI system relative to that of the conventional FM system. The results of incorporating the AMI into the AD-FALC system and a general comparison of the AD-FALC and conventional FM/FDM system performances are also discussed.

The testing was accomplished on a simplex basis, from DYE 4 to DYE 5. In addition to operational traffic, there were two outputs at DYE 5. The first was the test traffic from the three-voice-channel demultiplex test set hybridized with the conventional FM system, and the second was the test traffic from the three-voice-channel demultiplex test set hybridized with the AD-FALC system. This is indicated in Figure 3. Also shown is the loading of the three-voice-channel multiplex/demultiplex test sets of both systems. One channel carries 2400 b/s test data, another carries a 1 kHz tone, while the third is used to measure channel noise.

At all times, the conventional FM system was operated as quadruple space-frequency diversity using standard AN/FRC-39 equipments. The test system (AD-FALC) employed quadruple angle diversity from one antenna whose beams were arrayed in the vertical plane as described in the BTL report. In any event, voice channel performance of the systems was compared on the basis of 2400 b/s modem performance and median noise power performance.

Attempts were made to plot the modem performance as a function of median received carrier power. This attempt was unsuccessful because the performance was not directly related to the carrier power for either the test system or the conventional FM system. This is basically attributable to other sources of noise such as the path intermodulation noise, which not only acts to insert noise in the modem channel, but also causes an instability of the voice-channel modem signal. Other sources observed were from spurious emissions of the co-located transmitters, instability of the parametric amplifiers, and overloading of other channels.

1. TEST CONFIGURATION

The same problem encountered in testing the Adaptive FM system (AMI) against the conventional FM system (NO AMI) occurs when trying to test the AD-FALC-AMI system against the conventional FM: a simultaneous comparison is not possible. When AMI is imposed on the AD-FALC system, it is also unavoidable imposed on the

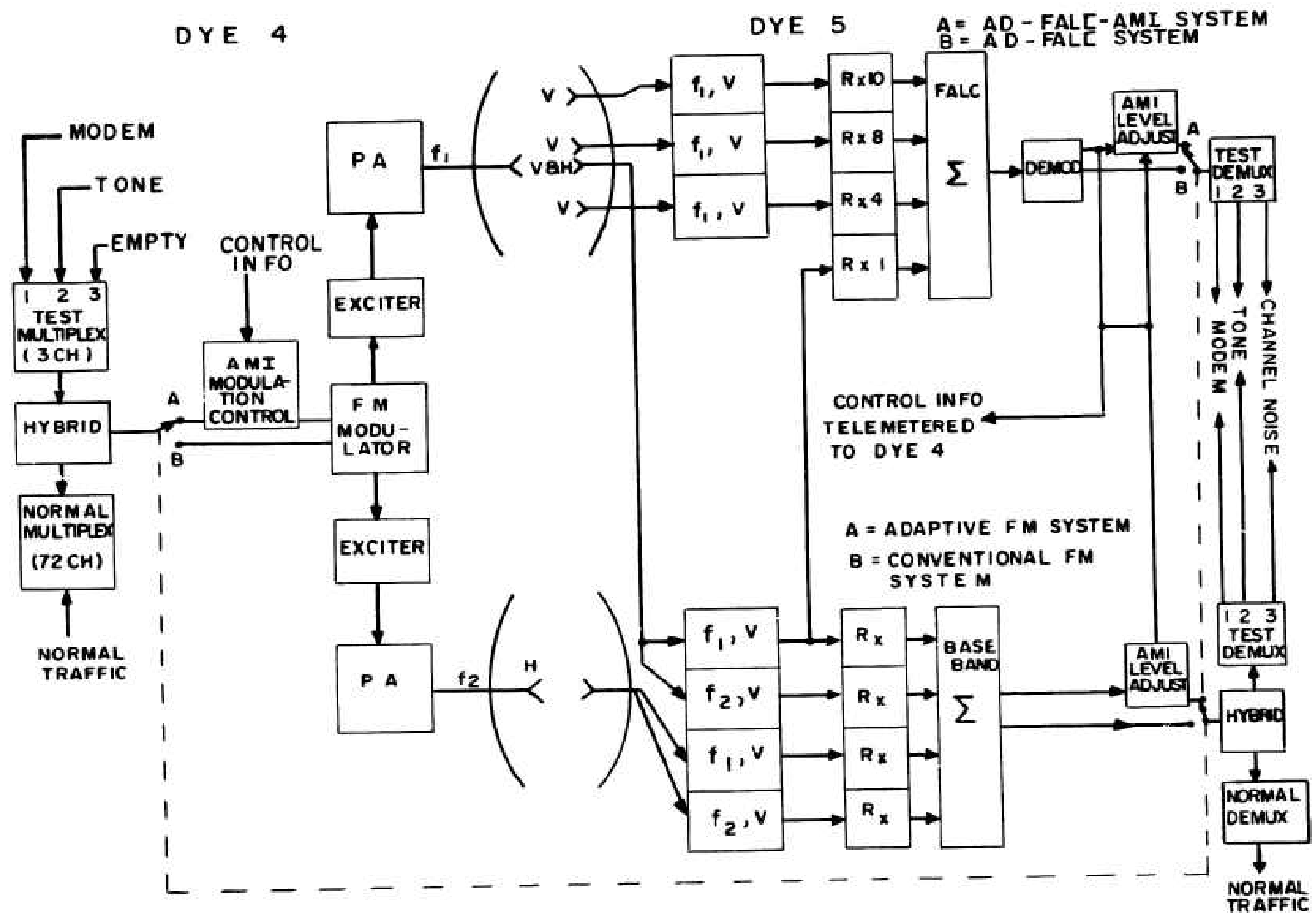

Figure 3. AD-FALC-AMI vs. Conventional FM Configuration

conventional FM system. Consequently, a comparison technique was selected imposing the AMI on both systems during alternate test periods. This technique established the basis for comparing statistically the performance of the test system with that of the conventional FM system. The experiment was performed during 105 test periods, each ten minutes long. The five-minute segment of each test period during which the AMI was activated is designated "TYPE A" tests. The alternate five minutes during which the AMI was not activated is designated "TYPE N" (Normal) tests. Thus simultaneous performance of AD-FALC-AMI and of the Adaptive FM (AMI) was achieved during a Type A test and of AD-FALC (NO AMI) and of the conventional FM (NO AMI) during a Type N test. This is illustrated in Table I.

TABLE I

Test Period	Test Type	System Configuration
1	A N	AD-FALC-AMI vs Conventional FM-AMI AD-FALC vs Conventional FM
2	A N	AD-FALC-AMI vs Conventional FM-AMI AD-FALC vs Conventional FM
3	A N	Same as A above vs same as A above Same as N above vs same as N above
| |	A N	| | | |
| |	A N	| | | |
105	A N	AD-FALC-AMI vs Conventional FM-AMI AD-FALC vs Convetional FM

.2. TEST RESULTS

In general, most of the data acquired from testing in accordance with the TABLE I illustration is presented in this report in terms of cumulative distribution curves. Regardless of whether the data analysis is in terms of the 2400 b/s modem performance or the voice channel median noise power performance, essentially four different cumulative distribution curves will be presented. These are:

1. Performance of the conventional FM system (without AMI)

2. Performance of the conventional FM system (with AMI)

3. Performance of the AD-FALC system (without AMI)

4. Performance of AD-FALC-AMI System

3. TEST RESULTS OF 2400 b/s MODEM

The performance of the 2400 b/s modem as operated through voice channels of the AD-FALC-AMI system and the CONVENTIONAL FM system is shown in Figure 4. The abscissa is the percent of the total test runs (105 per curve) or percent of the time that the 2400 b/s modem performance exceeds that which is indicated by the ordinate value.

These curves indicate that both systems performed poorly on a long term basis. Using a reasonable performance standard of say 1×10^{-5} or 1×10^{-4}, it is seen that these were achieved only 44 and 70 percent of the time, respectively, for the conventional FM system and only 12 and 47 percent of the time, respectively, for the AD-FALC-AMI system.

So although both systems performed poorly, it is obvious that in terms of 2400 b/s modem performance, the conventional FM system was superior to the AD-FALC-AMI system.

Figure 5 shows the long term 2400 b/s modem performance of the AD-FALC system (without AMI). Also shown are reprints of the AD-FALC-AMI and conventional FM curves. Comparing the AD-FALC and the AD-FALC-AMI distribution curves indicates better performance without AMI mainly because the AD-FALC curve does not degenerate to the poorest performance experienced by the AD-FALC-AMI.

Comparing the AD-FALC with the conventional FM system modem performance again indicates better performance is achieved most of the time by the conventional FM system. This could be expected since the power received by the boresight horns through which the conventional FM system operated should have more signal power than the angle-diversity feedhorns through which the AD-FALC system operated, unless of course the antenna system was not properly aligned.

On the other hand, however, the AD-FALC curve indicates it does not degenerate to the poorest performance experienced by the conventional FM system. The reason it does not is mainly attributable to an "abnormal" propagation condition which is explained in the following section.

"Normal" versus "Abnormal" Propagation Conditions

Propagation conditions were such that there were marked exceptions to the general rule that the boresight horns should have more received signal power than the off-set horns. The Appendix to this report implies two distinct modes of propagation.

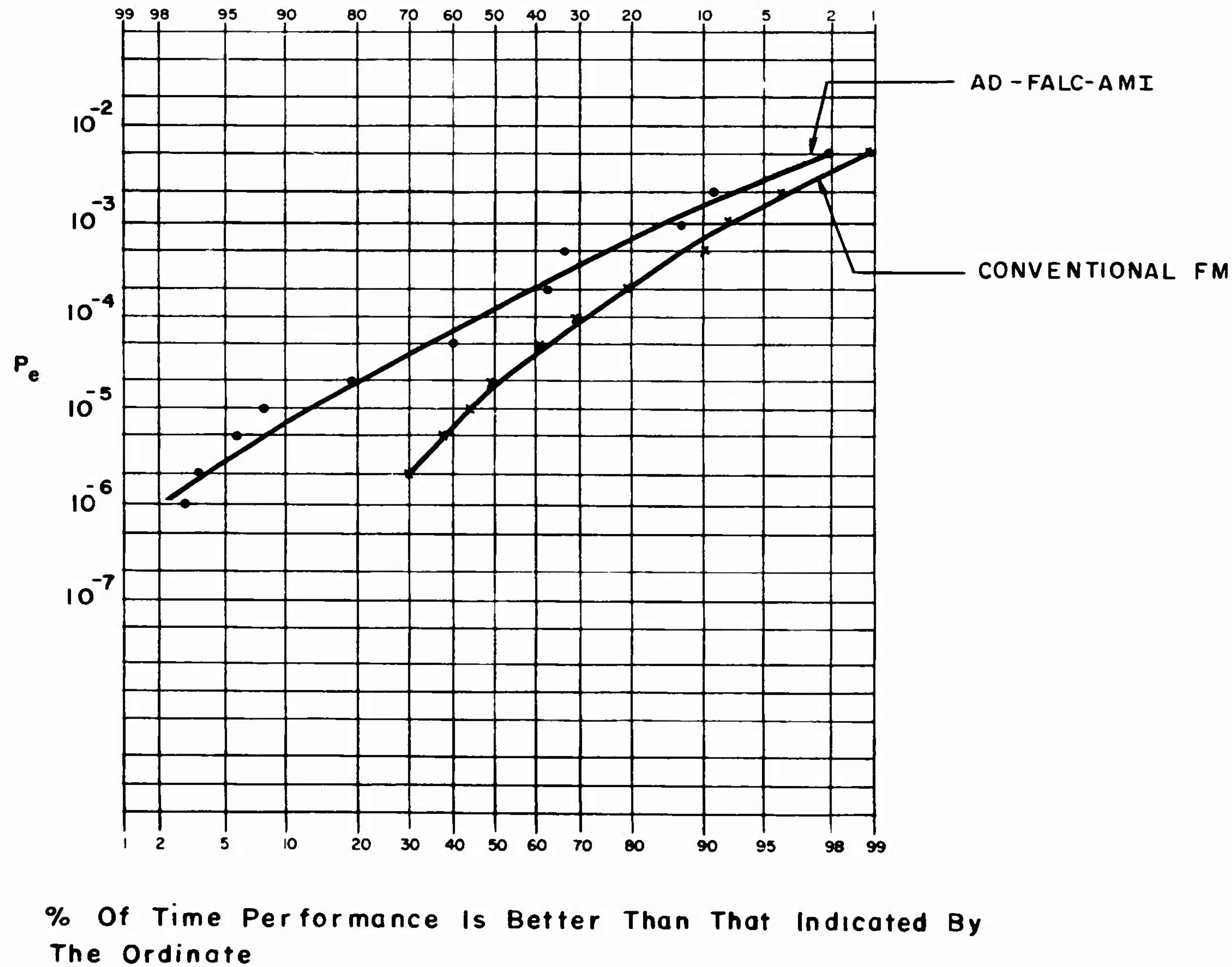

Figure 4. Distribution Function of the Performance of 2400 B/Sec Data Operated Through the AD-FALC-AMI and Conventional FM System

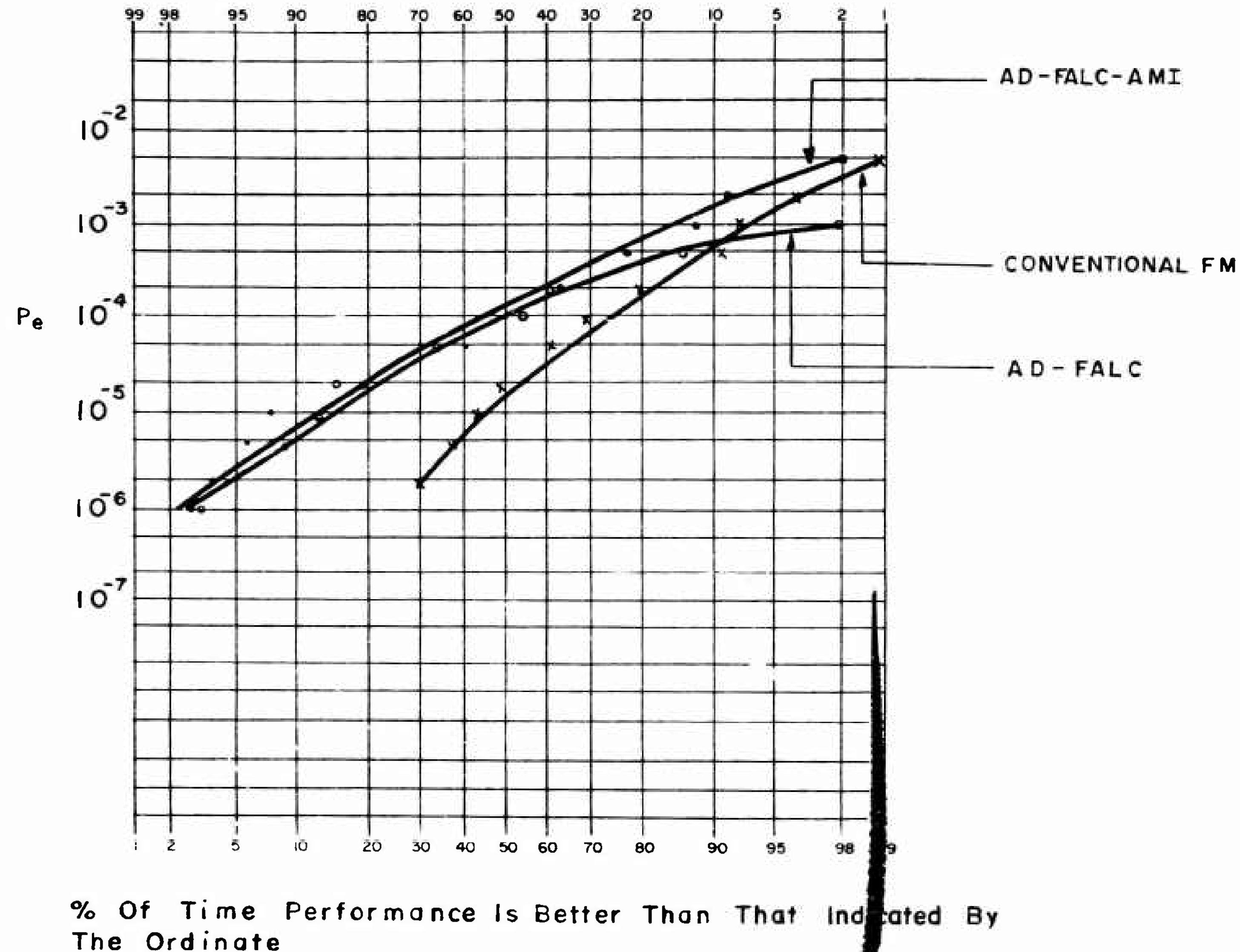

Figure 5. Distribution Function of the Performance of 2400 B/Sec Data Operated Through the ADC-FALC-AMI, AD-FALC, and Conventional FM System

The first mode, which is relevant to data taken on March 12, 14, 18, 20, and 26 may be characterized as "normal" propagation in that the distribution of median received signal power among all feedhorns is as expected. Here, the boresight horns have the most received signal power, while the off-set horns have less power, more or less in accordance with the path length associated with each horn. The second mode, relevant to the 13th of March data may be characterized as "abnormal" propagation. Here the received signal of the boresight horns is quite low, down to -100 dbm, while the signal into the off-set horns is as high as -82 dbm.

The frequency of occurrence of the two modes of propagation on a yearly basis is unknown. Presumably the "normal" mode predominates, but the occurrence of the "abnormal" mode is frequent enough to cause an outage condition of the conventional FM system which operates through the boresight horns. The occurrence of this mode was observed several times during the BTL/CSI testing: on February 20, February 22, and March 13, 1968. On all occasions, the following was observed:

1. The condition persisted from several hours up to a major portion of a day.

2. The signal received by the boresight horns, through which the conventional FM system operates, was very low, between -99 dbm and -110 dbm. This resulted in outage or very marginal performance of this system. This signal behavior on the boresight horns was invariably accompanied by relatively strong signals on the two off-set horns which straddle the boresight horn in the vertical plane. Consequently, the performance of the AD-FALC system was superior to that of the conventional FM system during such periods. For example, the average errors per bit of the AD-FALC system on the 13th of March was 3.4×10^{-4}, while for the conventional FM system it was 2.7×10^{-3}. Furthermore, on 22 February 1968, the signal on the boresight horns, through which the conventional FM system operated, was so poor that NARS system traffic was switched to the AD-FALC system as the only means of averting an outage condition.

3. The 13 March 1968 data also indicated that AD-FALC performance was better when the AMI was not used. For example, the average error per bit without the AMI was 3.4×10^{-4} and with the AMI operating it was 7×10^{-4}. There may have been instantaneous times when the AMI would have helped the AD-FALC system and, conversely, there may have been instances when the AMI would not help the AD-FALC, but would, in fact, degrade it. But since it was impossible to distinguish such times, it can only be said that better performance resulted when the AMI was not in operation. This leads to the conclusion that the superior performance of the AD-FALC-AMI system compared to that of the conventional FM system, during the period of abnormal propagation was not due to the AMI, nor to the FALC, but to the angle-diversity aspect of the test system.

The cause of the abnormal mode of propagation is unknown. Since the condition persisted for at least several hours at a time, and since a signal degradation on the boresight horn system was accompanied by relatively strong signals on the off-set horns, it is suspected that the phenomena is due to a vertical displacement of a strong inversion layer. This would have a great influence on the magnitude of the vertical angle through which scatter/reflected signals arrive at the receive antenna. Aside from other factors such as adjacent-transmitter noise, unstable parametric amplifiers, path internodulation noise, etc., the abnormal mode of propagation may well be a major factor in the poor performance of the conventional FM system on a long term/ yearly basis.

Concerning the normal mode of propagation, the data taken on the 12th, 14th, 18th, 20th, and 26th of March 1968 applies. The following table shows the average daily error rate performance of the 2400 b/s data through each of the systems.

TABLE II

	AD-FALC-AMI	AD-FALC	CONVENTIONAL FM
12 March	1.4×10^{-4}	3.3×10^{-4}	6.3×10^{-5}
14 March	4.3×10^{-4}	2.8×10^{-4}	1×10^{-4}
18 March	7.4×10^{-4}	1.7×10^{-4}	6.8×10^{-5}
20 March	1.3×10^{-4}	1.3×10^{-4}	1.3×10^{-4}
26 March	1.4×10^{-3}	3.1×10^{-4}	7×10^{-5}

From the above table the conventional FM system is clearly superior to the AD-FALC or AD-FALC-AMI at least with regard to modem performance.

Also, again discussing modem performance, there is no consistent pattern indicating the AMI helps or degrades the AD-FALC system. On two days, better performance is achieved when AMI is used, on two other days the opposite is true, and on the fifth day the two are equal. The extent to which AMI helped the AD-FALC was from 1:1 up to 4.3:1; conversely the extent to which AMI degraded the AD-FALC modem performance was from 1:1 up to 4.5:1. Consequently, the use of AMI with AD-FALC is undesirable for cases where this system could be carrying a heavy modem load. Certainly no adjunct system should be allowed to degrade the performance of the basic system beyond what could be achieved without it.

4. TEST RESULTS REGARDING VOICE CHANNEL NOISE PERFORMANCE

Voice channel noise performances of the AD-FALC-AMI system and the conventional FM system are shown in Figure 6. The distribution curves are those of voice channel median noise power for the same test runs as the 2400 b/s data analysis. These curves indicate that during the six days of these tests, the conventional FM

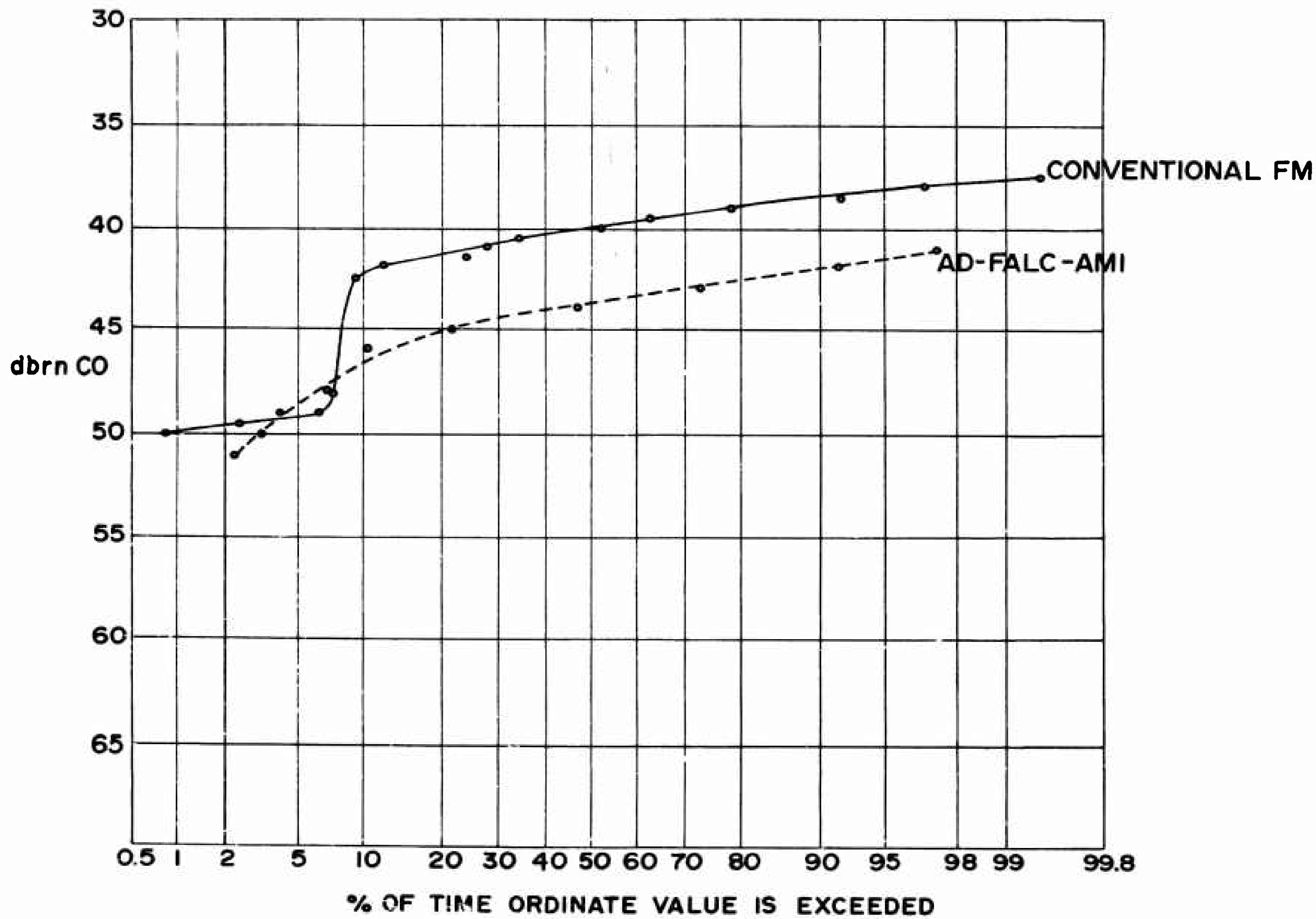

Figure 6. Distribution Function of Voice Channel Median Noise Power of 2400 B/Sec Data on AD-FALC-AMI and Conventional FM System

system out-performed the AD-FALC-AMI by about 4 db for at least 90 percent of the time. The abnormally high channel noise on the conventional FM system the other ten percent of the time is attributed to the poor propagation condition existing on the boresight beams on 13 March 1968.

Figure 7 shows the effect the AMI had on the AD-FALC system. The distribution curves are those of voice channel median noise power for the AD-FALC system with and without AMI. They indicate that on a long-term basis better performance is achieved when the AMI is not used.

Figure 8 shows the effect the AMI had on the conventional FM system. Again, the distribution curves are those of voice channel median noise power with and without AMI. And again, the curves indicate better performance without the AMI. However, it is only fair to point out that this effect may be misleading, because for this series of tests the AMI was adapted to the AD-FALC system, which does not necessarily imply an optimum adaptation to the boresight FM system.

Having shown that it would be undesirable to incorporate the AMI into the AD-FALC system, Figure 9 shows the projected noise performance which should result if the AD-FALC system was expanded 4 fold in diversity by implementing bi-polarized receive feedhorns on both space diversity antennas. Comparing this projected distribution with the boresight-conventional FM, a 2 db noise improvement is achieved most of the time. But more importantly, there is a drastic improvement in the noise performance during the time the boresight system is most vulnerable, i.e., during "abnormal" propagation conditions.

5. CUMULATIVE DISTRIBUTION OF MODULATION INDEX

Figure 10 compares cumulative distribution plots of the Modulation Index imposed on both the AD-FALC and conventional FM system by the AMI device during the type "A" tests. (Bear in mind this is adapted on the AD-FALC system but only inadvertently imposed on the conventional FM system.)

The lower distribution curve plots the median values of Modulation Index per test run. Remembering that the operational FM system employs a modulation index of 3, this lower curve indicates the AD-FALC system is receptive to a median modulation index of less than 3 for 80 percent of the time, even though the slope of this curve indicates no specific overriding preference of Modulation Index. If a choice had to be made of the amount of modulation index, it would probably be the median value of 2.4 resulting in 2 db less signal power per voice channel.

The upper curve is a cumulative distribution of the Modulation Index which is exceeded for 3 percent of the time per test run. It is presented primarily to indicate the extent of activity of the AMI device.

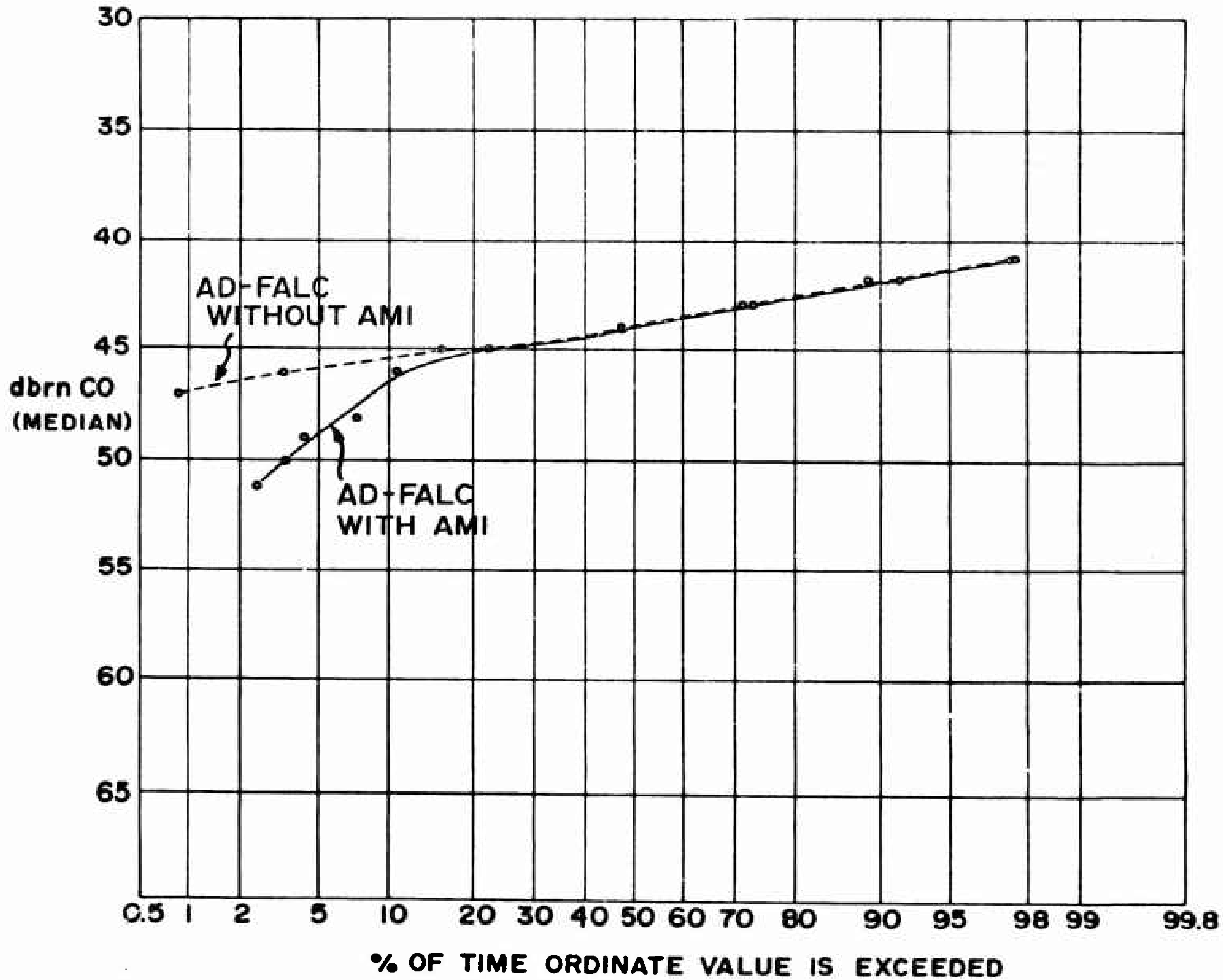

Figure 7. Distribution Function of Voice Channel Median Noise Power of 2400 B/Sec Data for AD-FALC System With and Without AMI

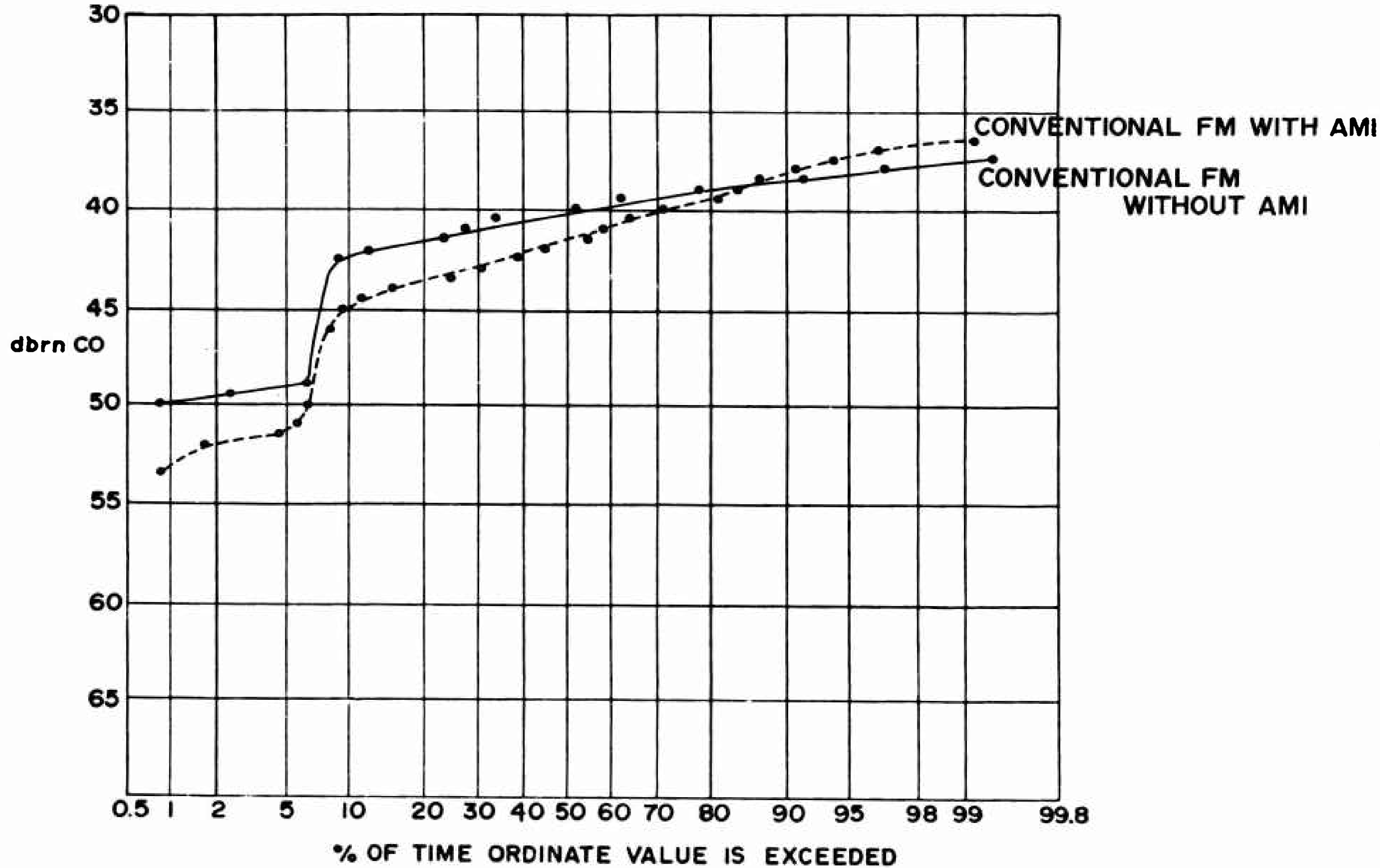

Figure 8. Distribution Function of Voice Channel Median Noise Power of 2400 B/Sec Data for FM System With and Without AMI

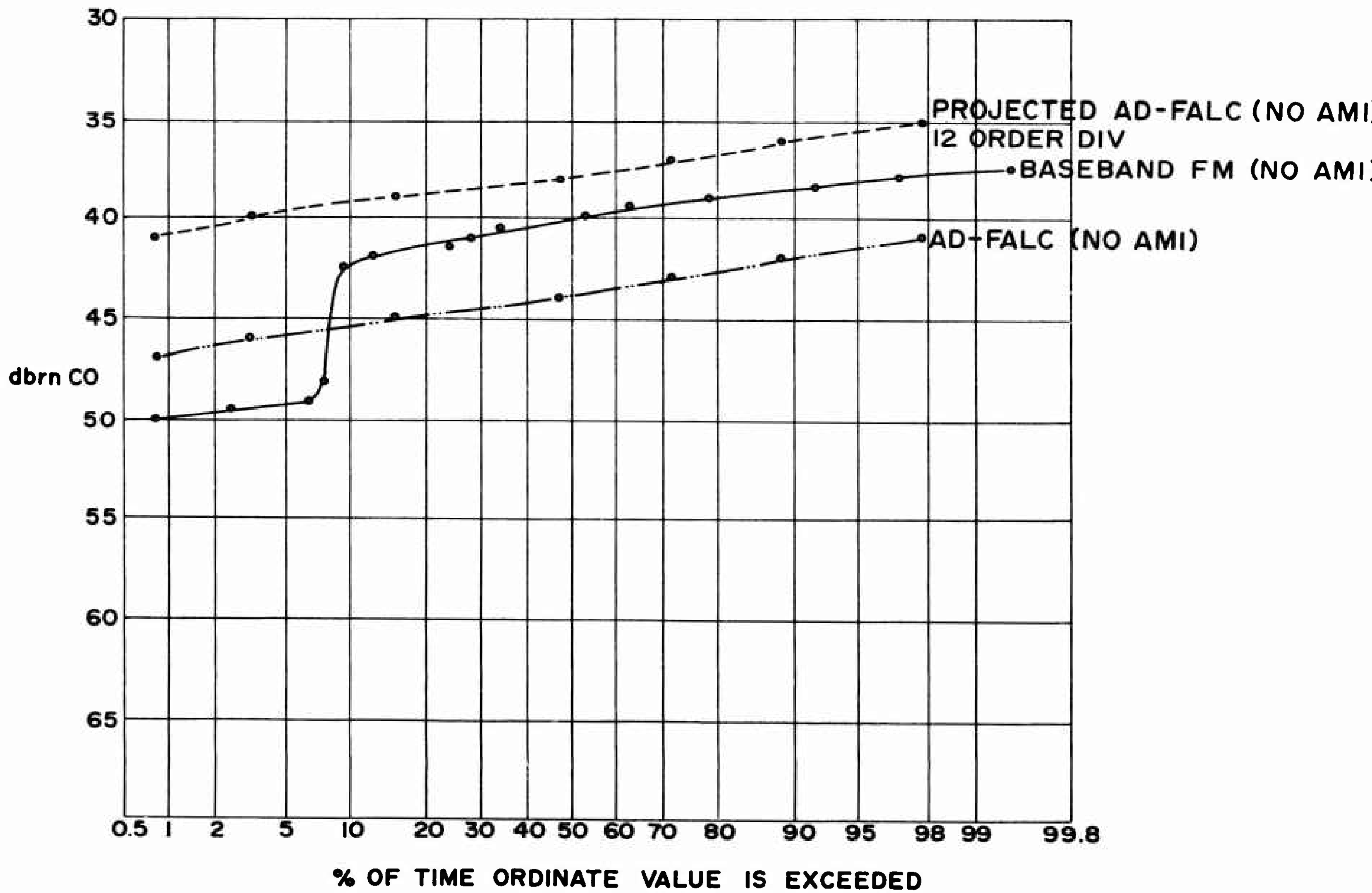

Figure 9. Distribution Function of Voice Channel Median Noise Power and Projected Noise Performance of 2400 B/Sec Data on the AD-FALC System Without AMI

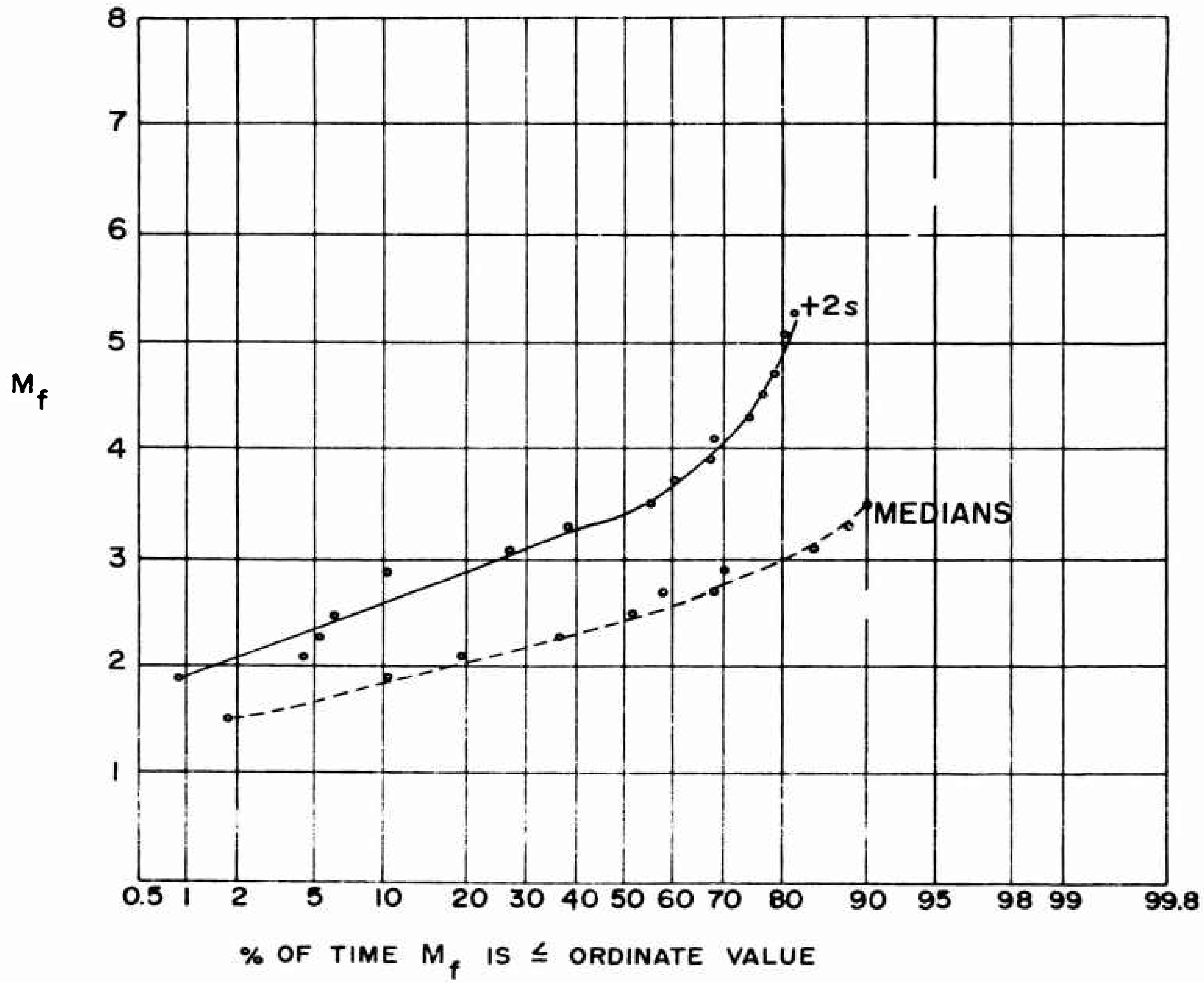

Figure 10. Cumulative Distribution of the Modulation Index Medians Controlled by the AMI Device on Both Conventional FM and AD-FALC System

SECTION III

AD-FALC-PDC TESTING

Testing was performed under various diversity conditions to provide comparative data under the same troposcatter conditions. Figures 11 through 13 represent plots of BER taken in five-minute periods for the Baseband and the AD-FALC system. Figure 11 shows both the Baseband and FALC system operated in a quad diversity mode. The FALC weighting circuit was not used during this test and the Baseband system made approximately four times as many errors as the FALC system. The test lasted approximately eight hours.

When the FALC system was configured for a six-way diversity scheme, large improvements in BER were recorded. Figures 12 and 13 show improvements in BER approximating 24 to 1 and 8 to 1, respectively. These tests were approximately 18 hours each and the signal levels during these periods were consistent throughout the test and measured as follows: Horn 1N - 87 dbm, 4N - 95 dbm, 8N - 90 dbm.

Figures 14 through 17 represent the results of the Baseband (Conventional System) and Raytheon PDC tests. Figure 14 reveals that the same number of errors were made by both systems during quad-diversity testing (4th order space-frequency diversity). Although the signal level during this period was high, about 85 dbm, the intermodulation was also high and, therefore, accounted for the large number of errors made by both systems. Figure 15 depicts another quad-diversity test performed during low intermodulation conditions. The result of this test revealed the baseband system BER to be greater than the PDC system by a factor of 9 to 1. Figure 16 represents a plot of BER in five-minute periods showing concentrations of errors about various ratios. For example, a heavy concentration of BER occurs when the BB system makes ten times as many errors as the PDC system, or at a BB to PDC error ratio of ten. The largest concentration of BER occurs between the ratios of 10 to 100 and has a median value near the 25 ratio line.

When the Raytheon PDC system operated in a six-way diversity mode, large improvements in BER resulted. Figure 17 represents this condition and illustrates the performance of the PDC angle-diversity system against the BB quad-diversity system. The BB system made approximately seven times as many errors as the PDC system.

Figures 18 to 22 represent the results of the Raytheon PDC and Bell Telephone Laboratories FALC tests. Figures 18 and 19 are plots of Raytheon's PDC operating in a six-way angle-diversity mode versus the FALC system operating in a quad-diversity mode.

Figure 18 depicts the BER results when the PDC operated without their echo detector circuit and the FALC system eliminated their weighting and intermodulation circuits. The outcome of this test resulted in the FALC system making five times as many errors as the PDC system. When Raytheon operated with their echo detector, a large improvement in BER occurred. The results of this test are shown in Figure 19. When both systems were operated in a six-way diversity mode and the FALC system was operating without the intermodulation circuit, the test results were about the same, as shown in Figure 20.

Further six-way diversity testing resulted in the PDC accumulating less errors than FALC system. Examination of Figure 21 reveals the FALC system making approximately ten times as many errors as the PDC system during this test period.

The distribution of FALC error rates to PDC error rates as presented in Figure 22 reveals that 34 percent of the time the FALC angle diversity system made less errors than the PDC system.

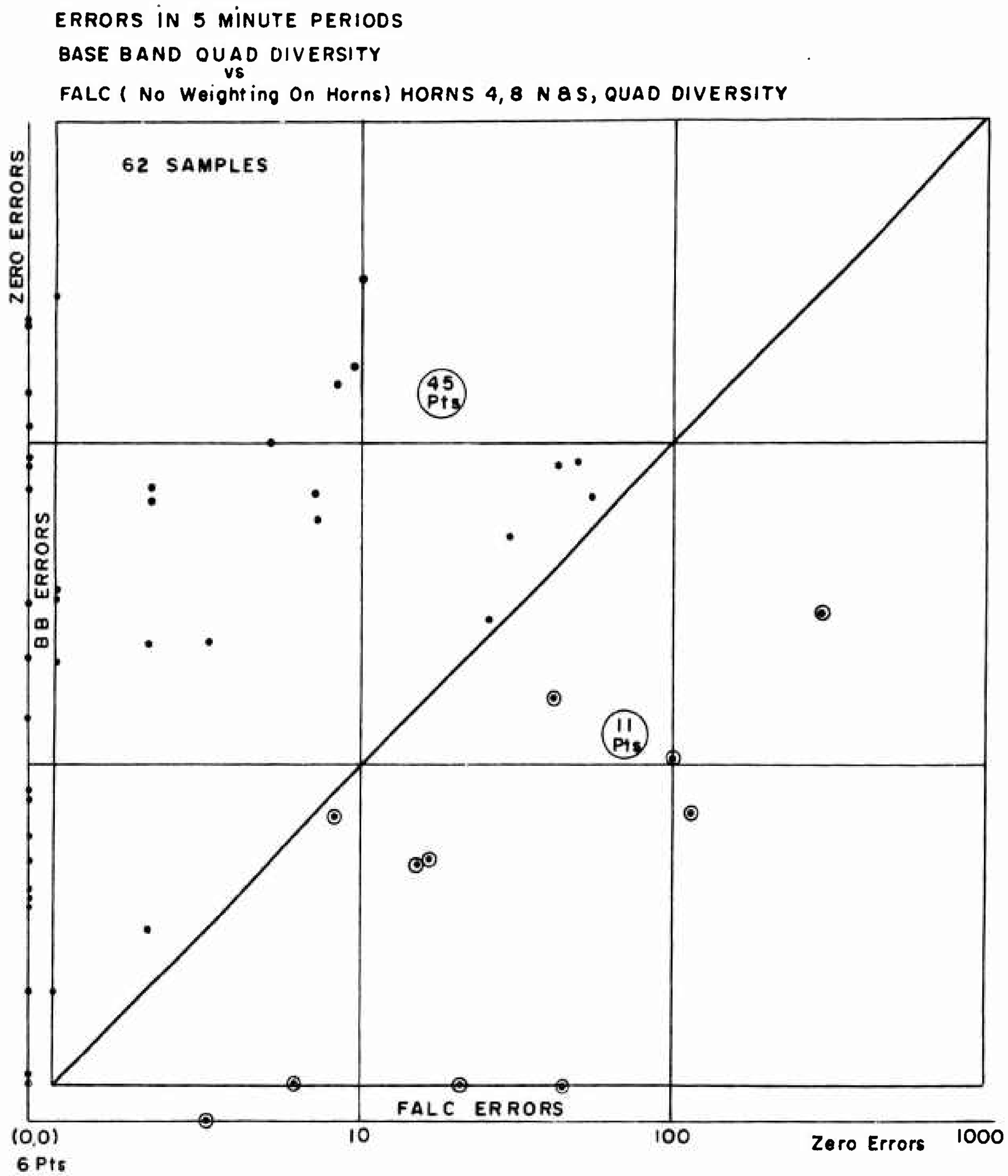

Figure 11. Baseband Quad Diversity vs. FALC Quad Diversity

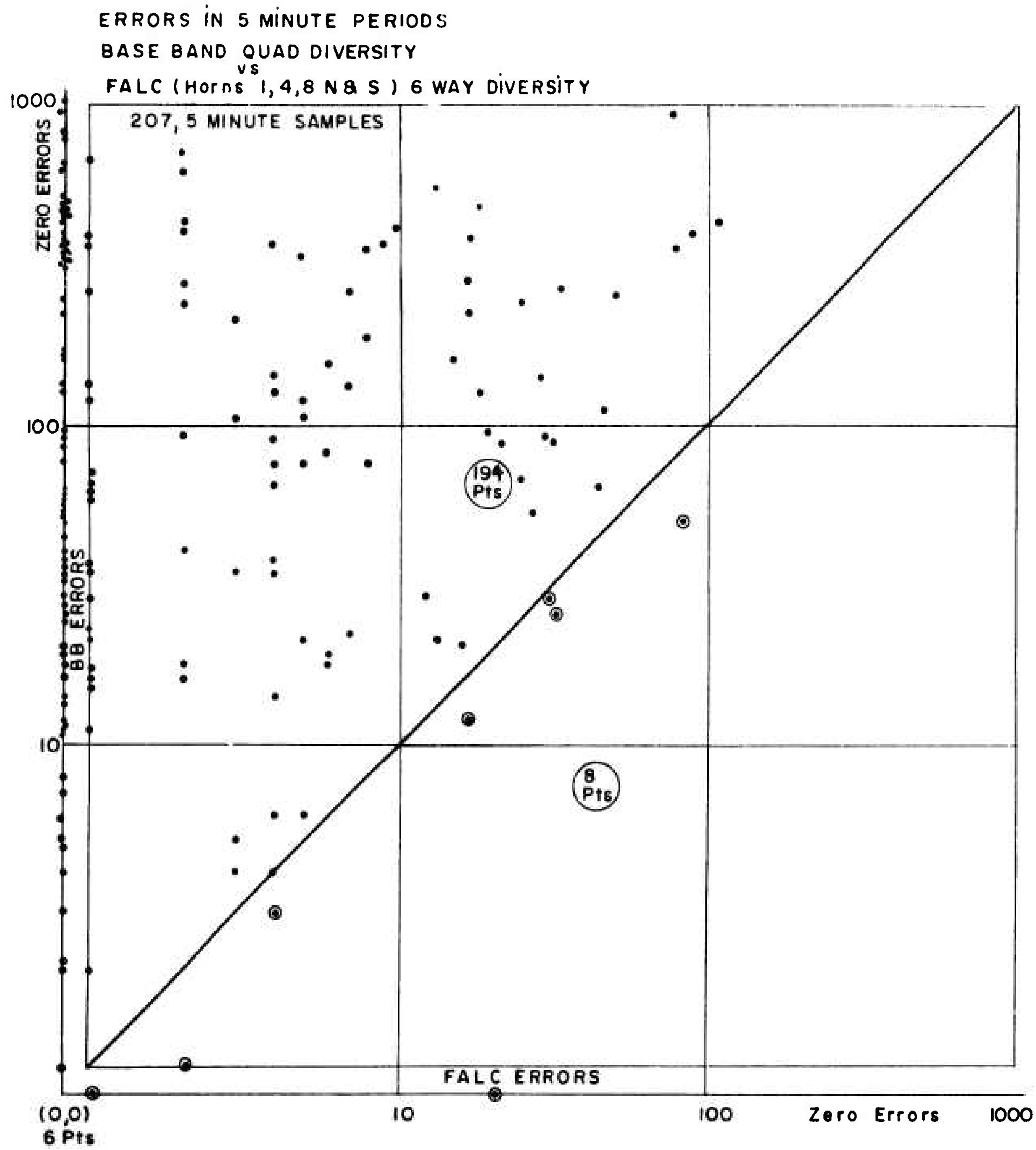

Figure 12. Baseband Quad Diversity vs. FALC 6-Way Diversity

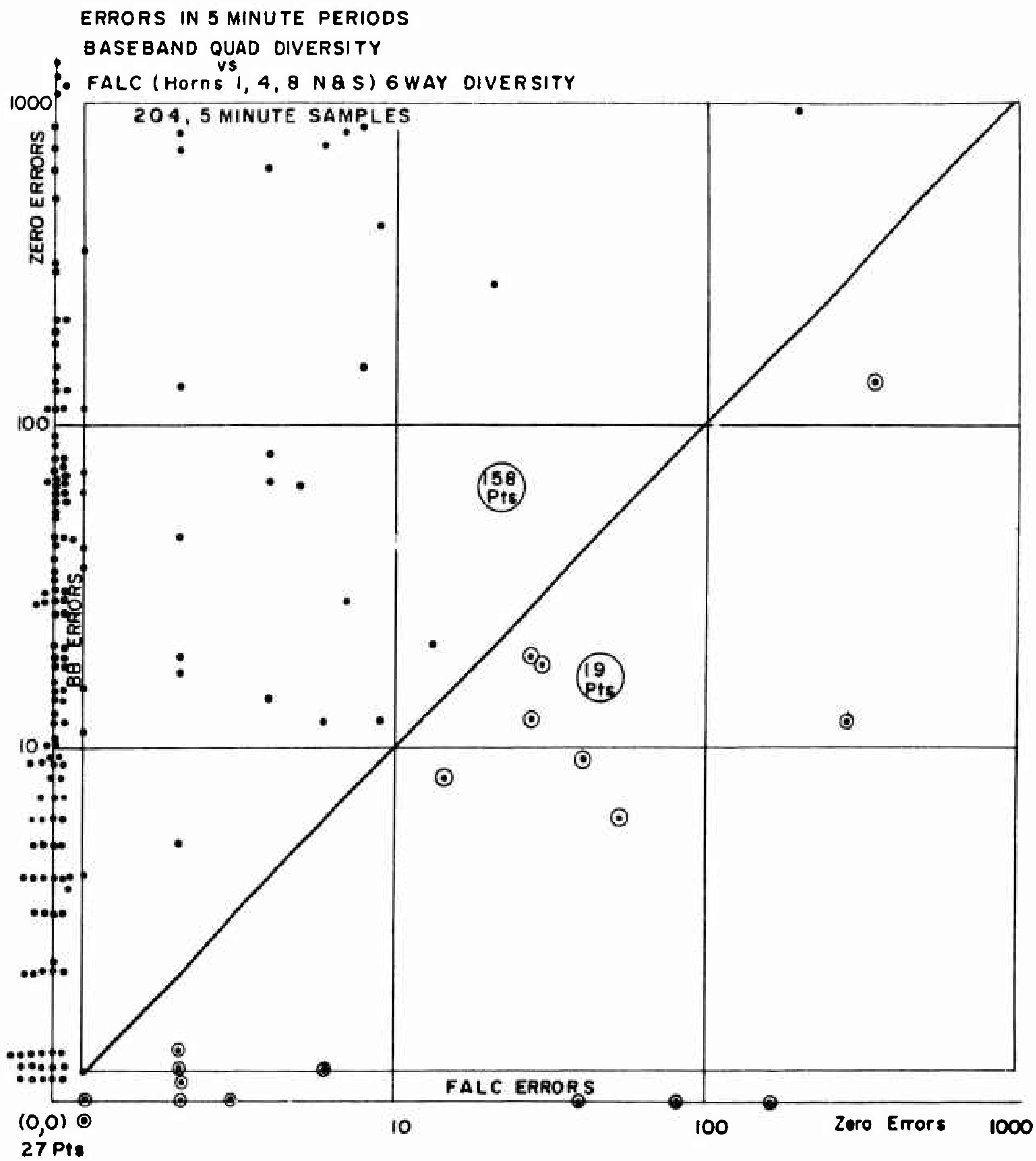

Figure 13. Baseband Quad Diversity vs. FALC 6-Way Diversity

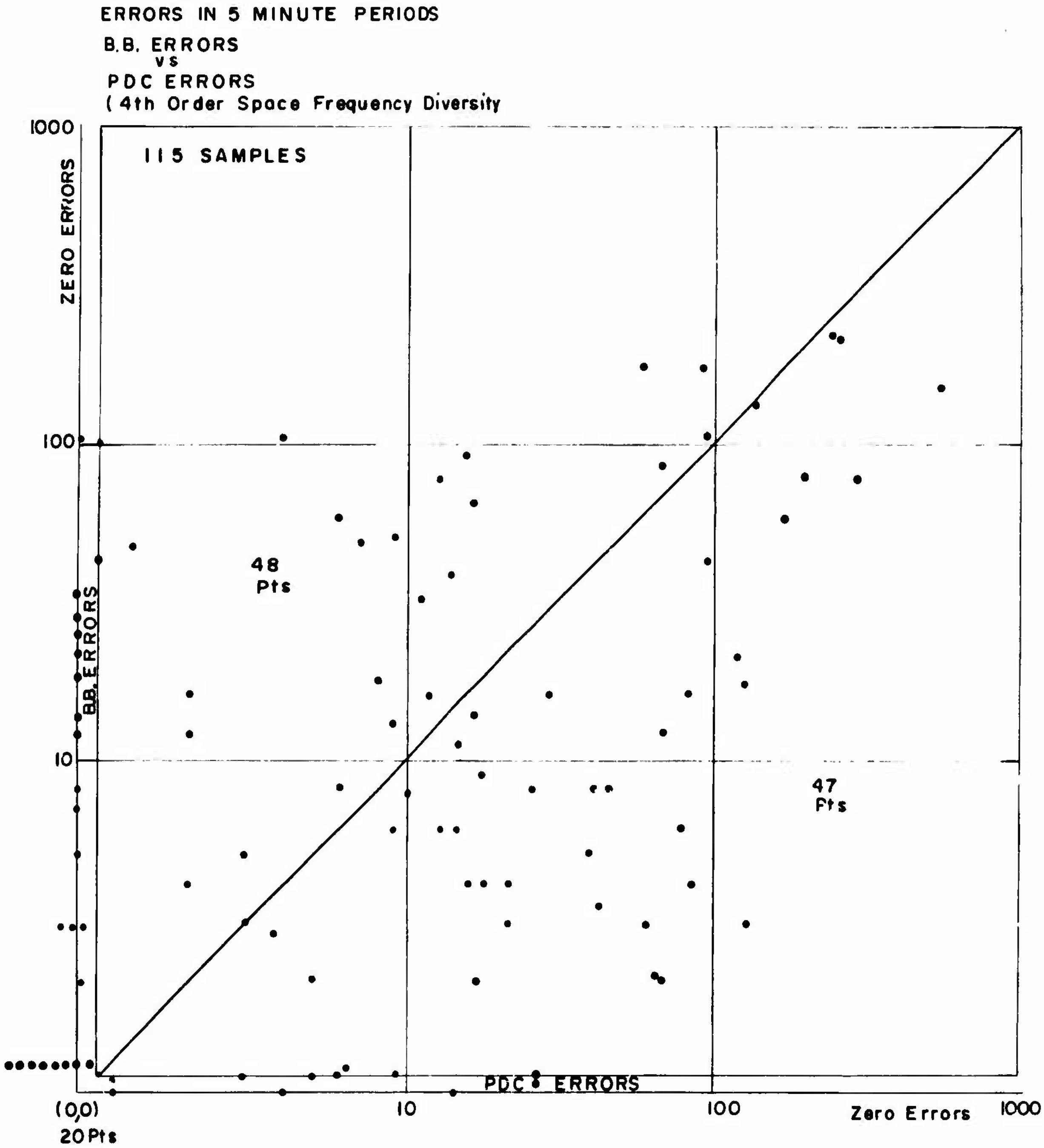

Figure 14. Baseband Quad Diversity vs. PDC Quad Diversity

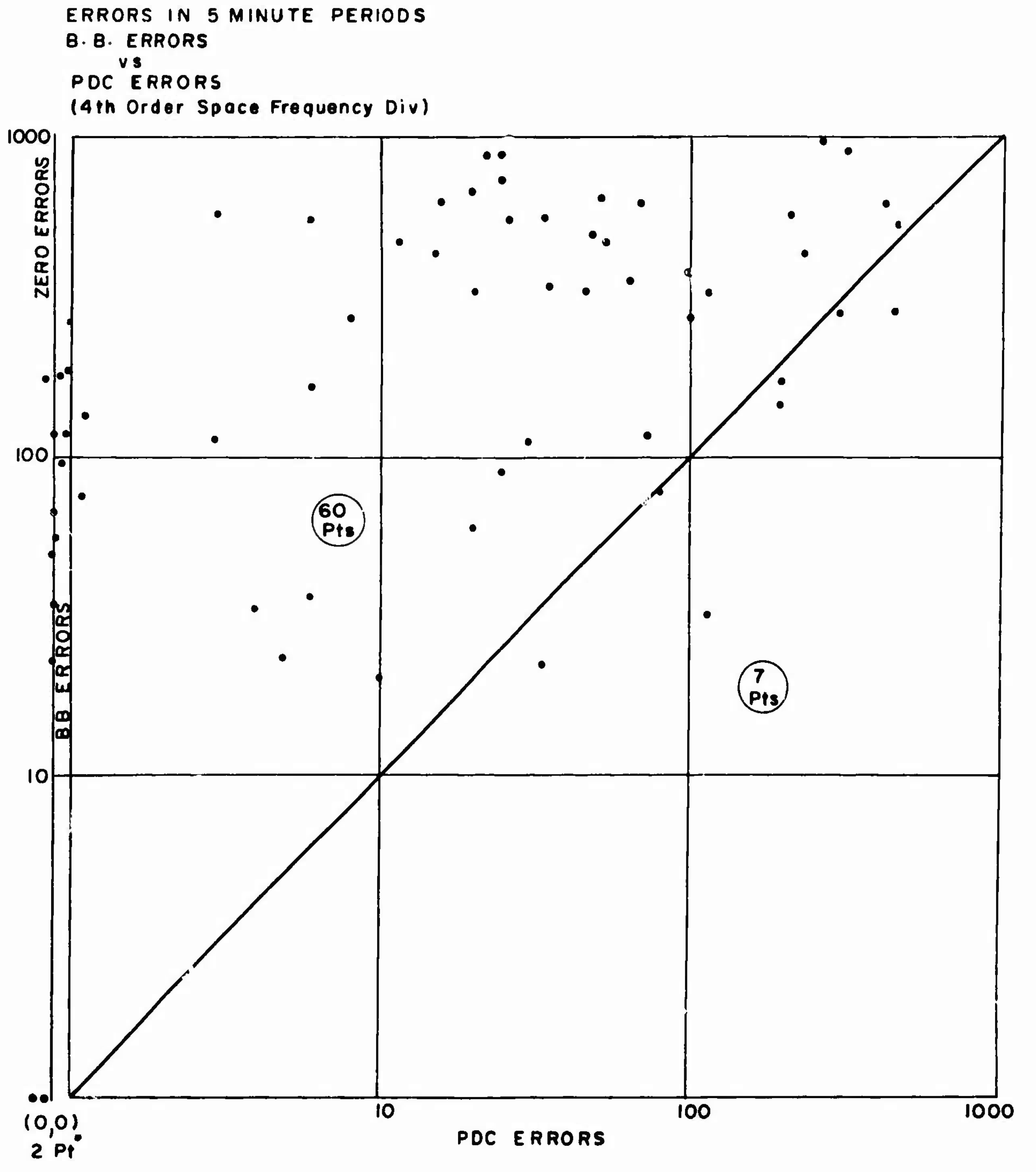

Figure 15. Baseband Quad Diversity vs. PDC Quad Diversity

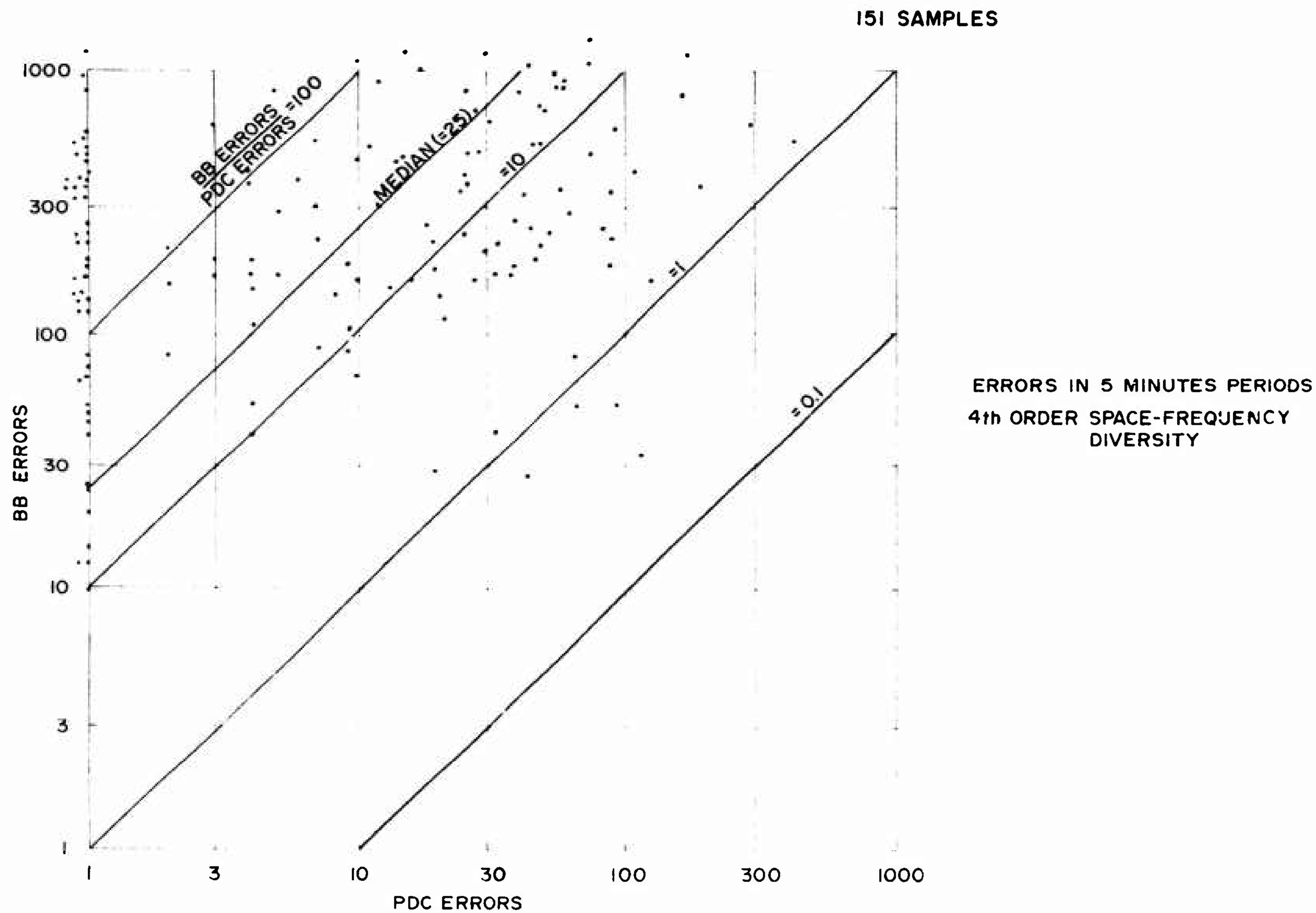

Figure 16. Baseband Quad Diversity vs. PDC Quad Diversity

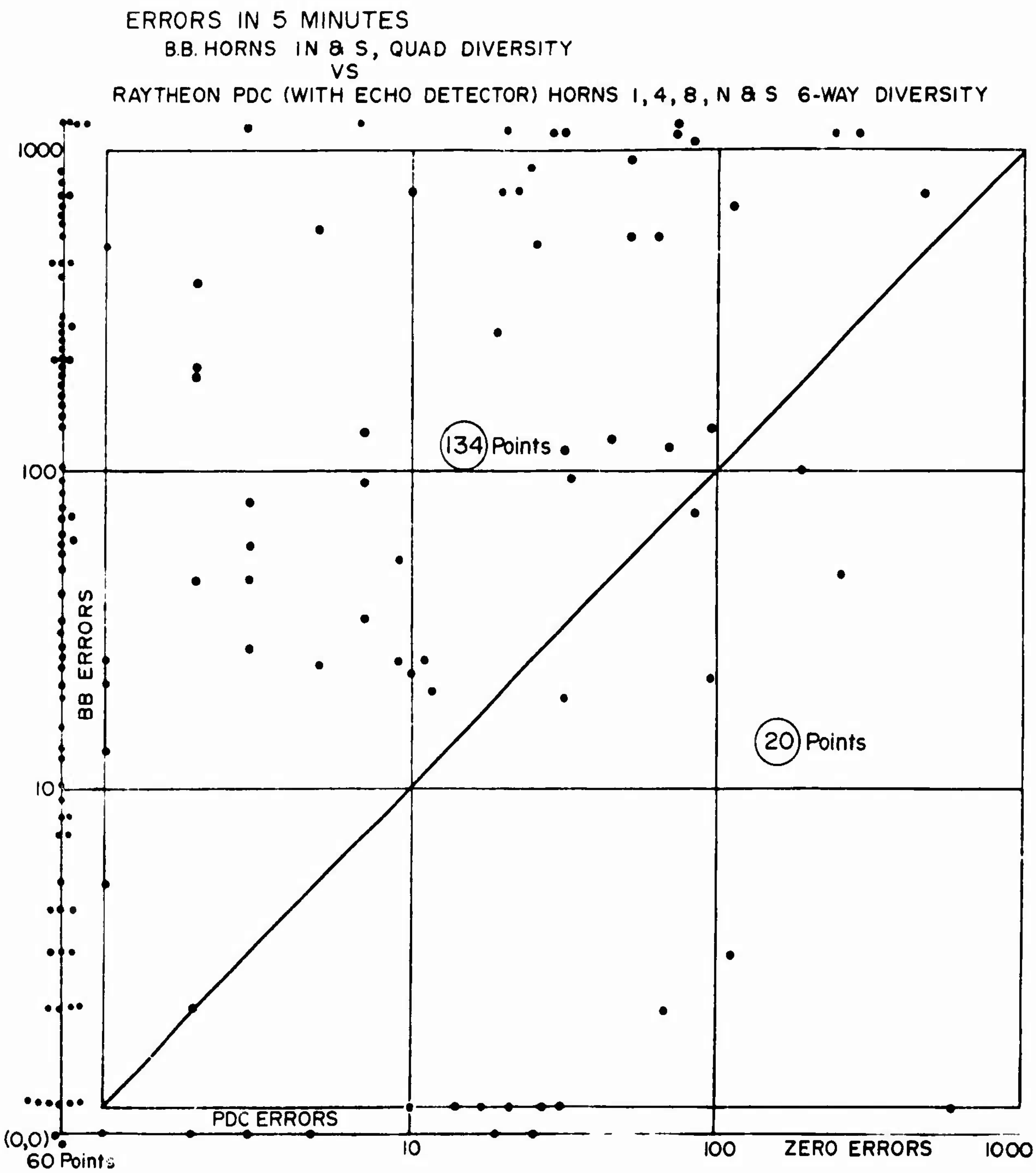

Figure 17. Baseband Quad Diversity vs. PDC 6-Way Diversity

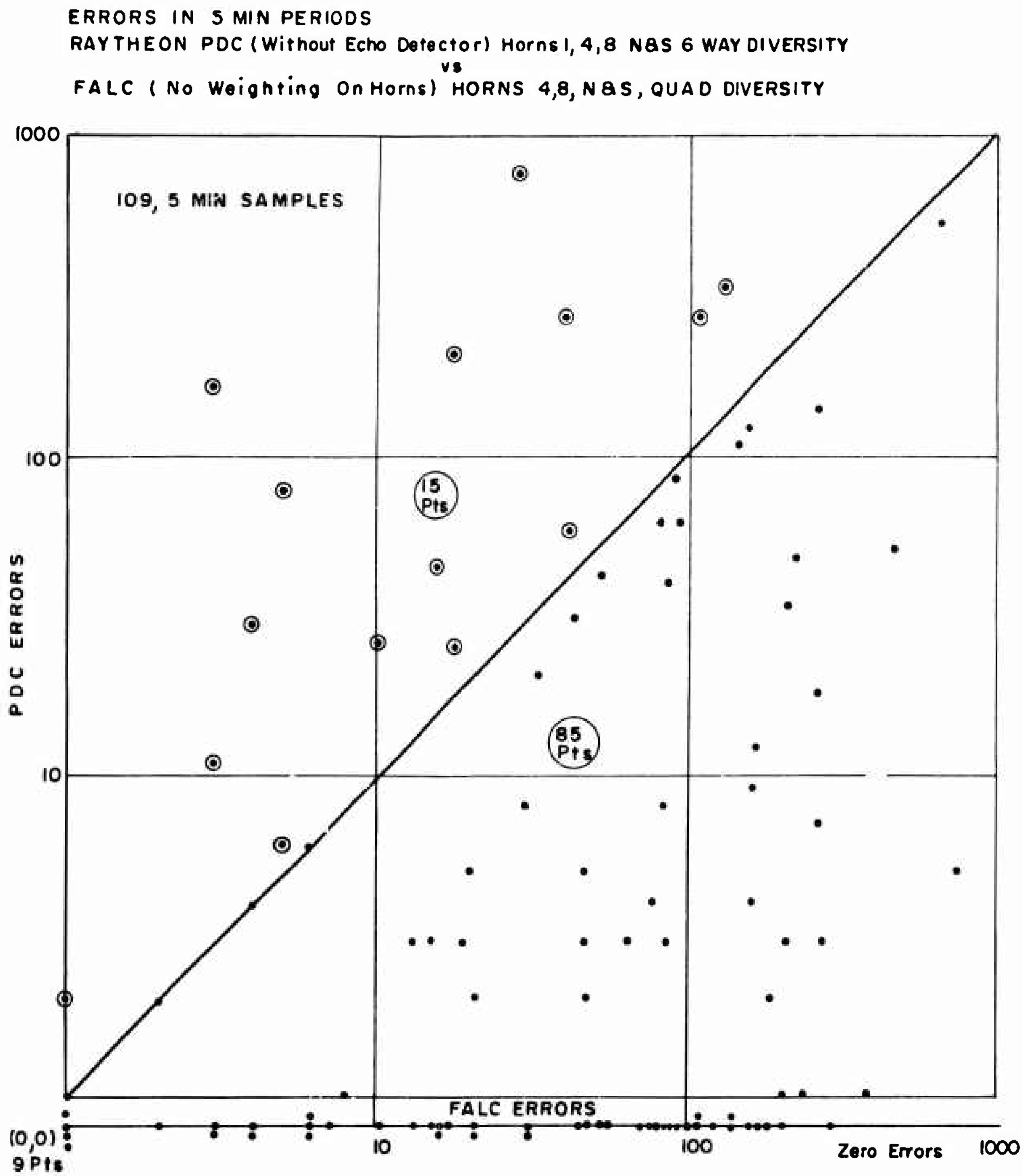

Figure 18. PDC 6-Way Diversity vs. FALC Quad Diversity

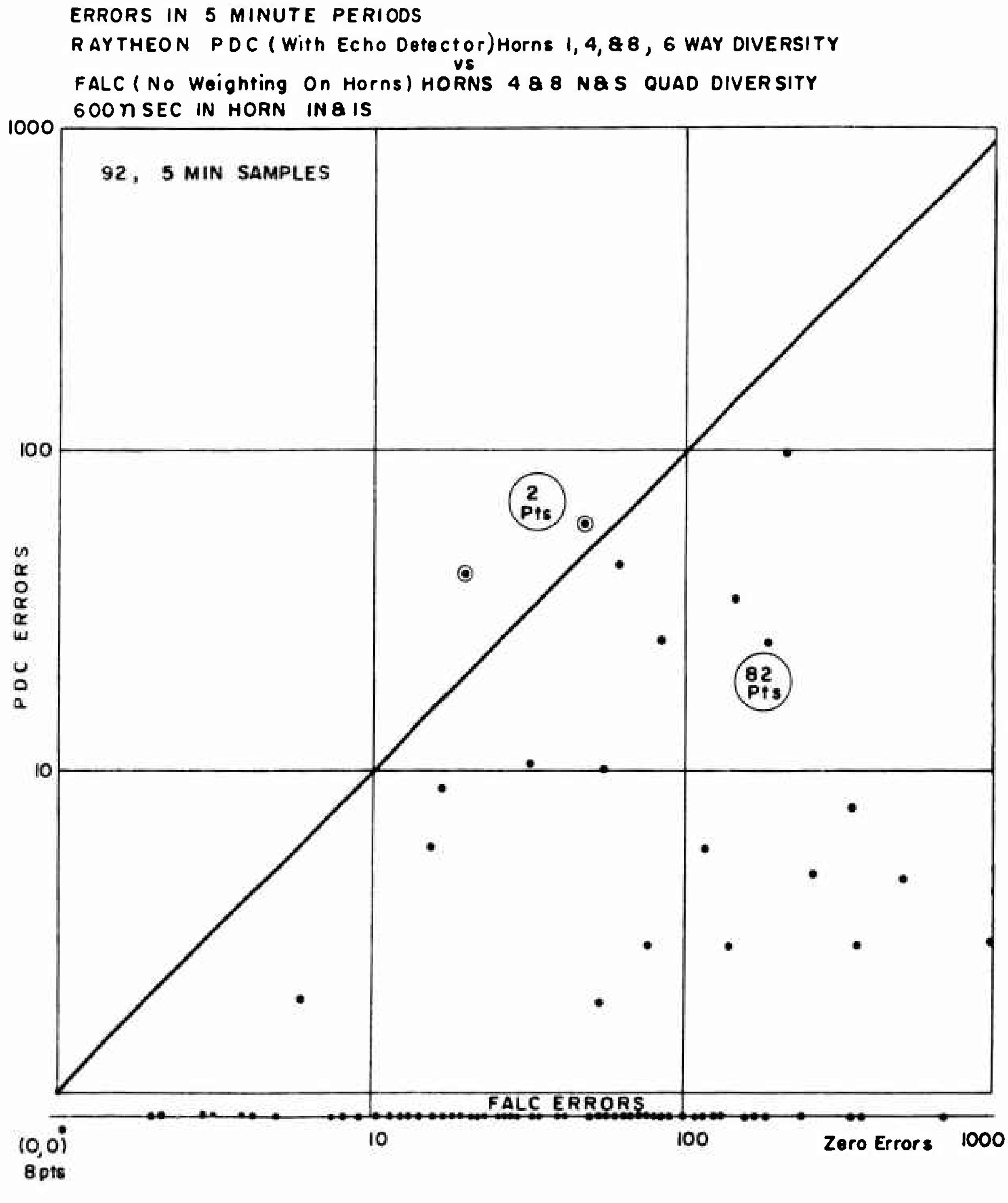

Figure 19. PDC 6-Way Diversity vs. FALC Quad Diversity

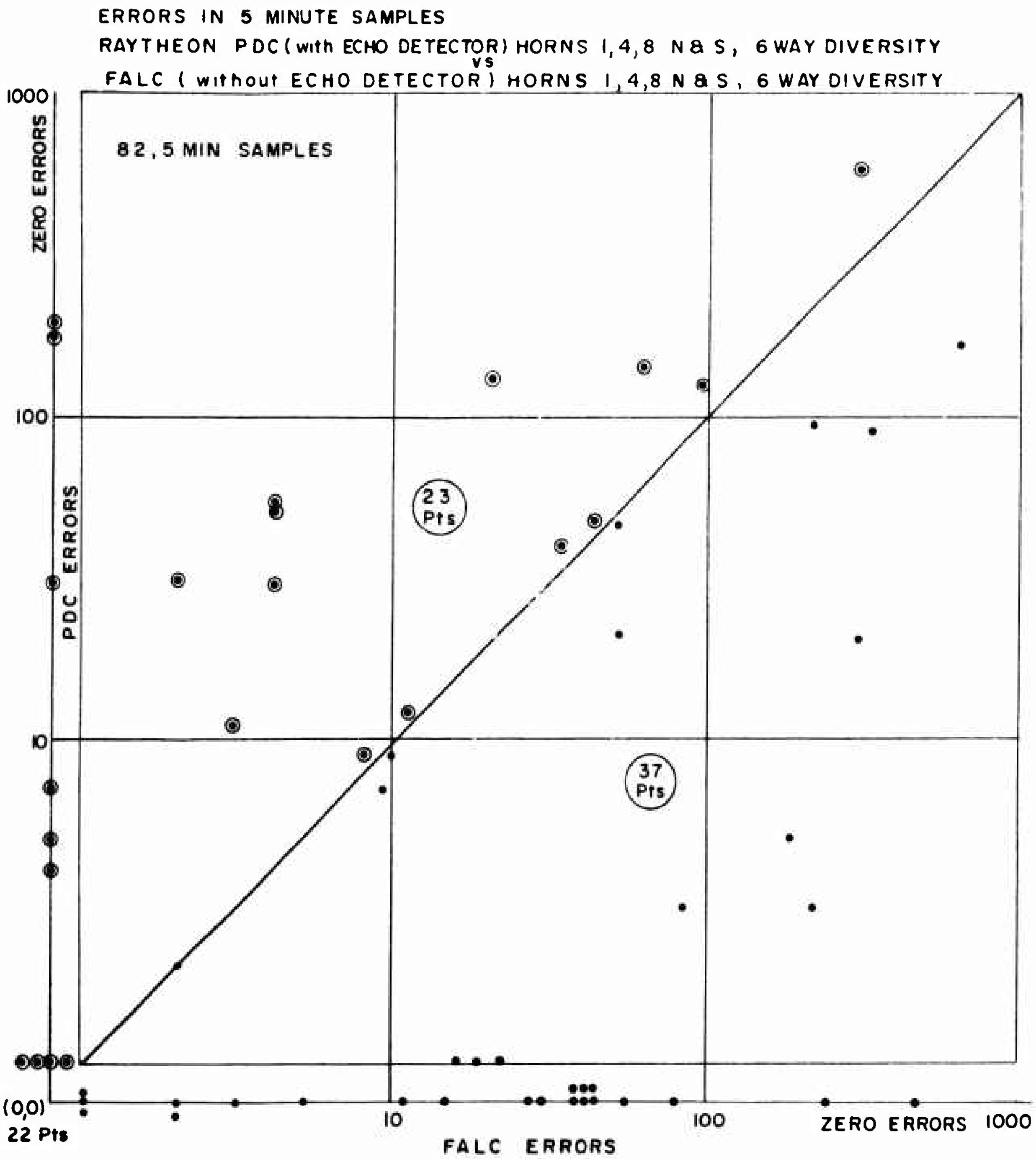

Figure 20. PDC 6-Way Diversity vs. FALC 6-Way Diversity

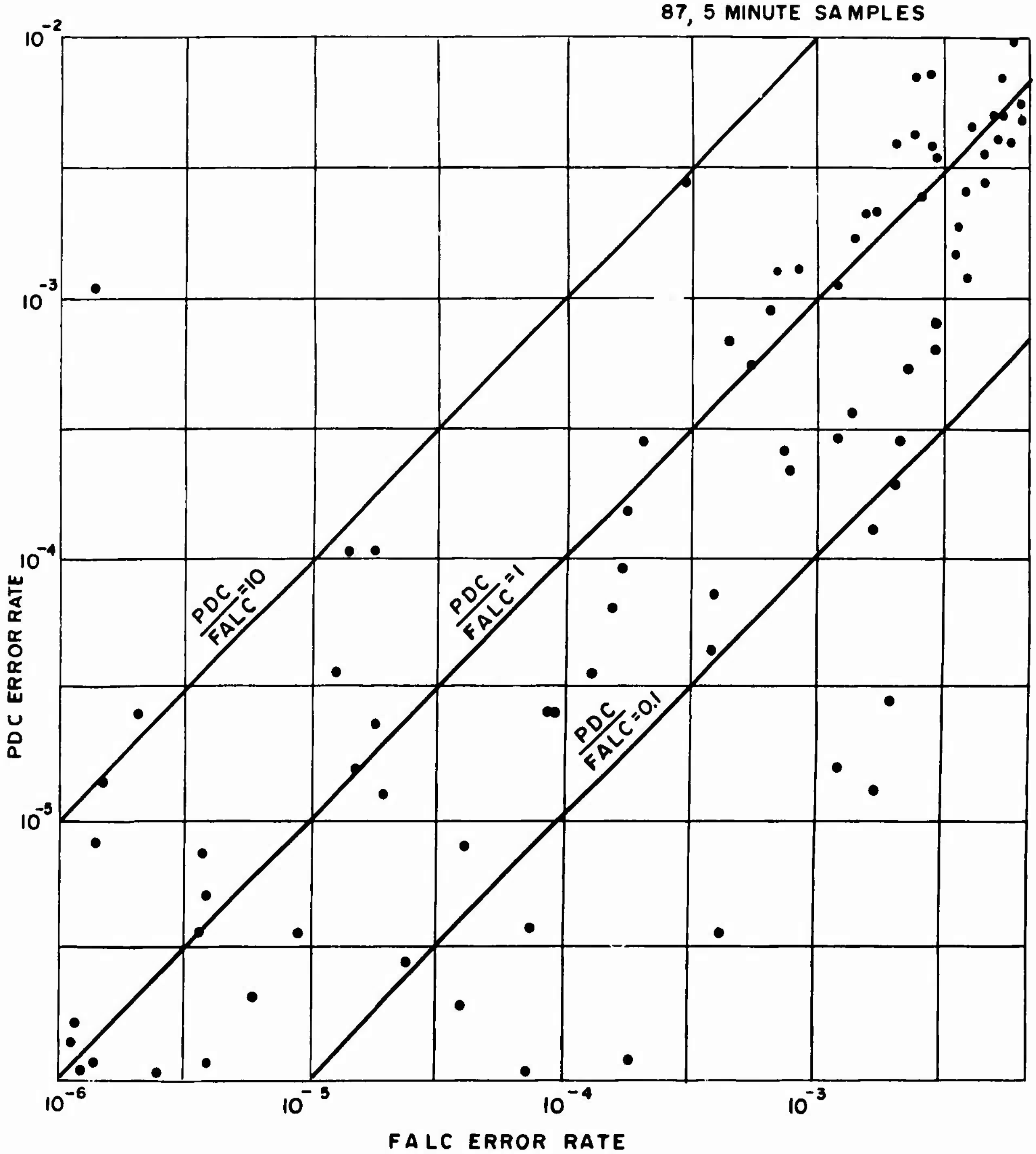

Figure 21. PDC 6-Way Diversity vs. FALC 6-Way Diversity

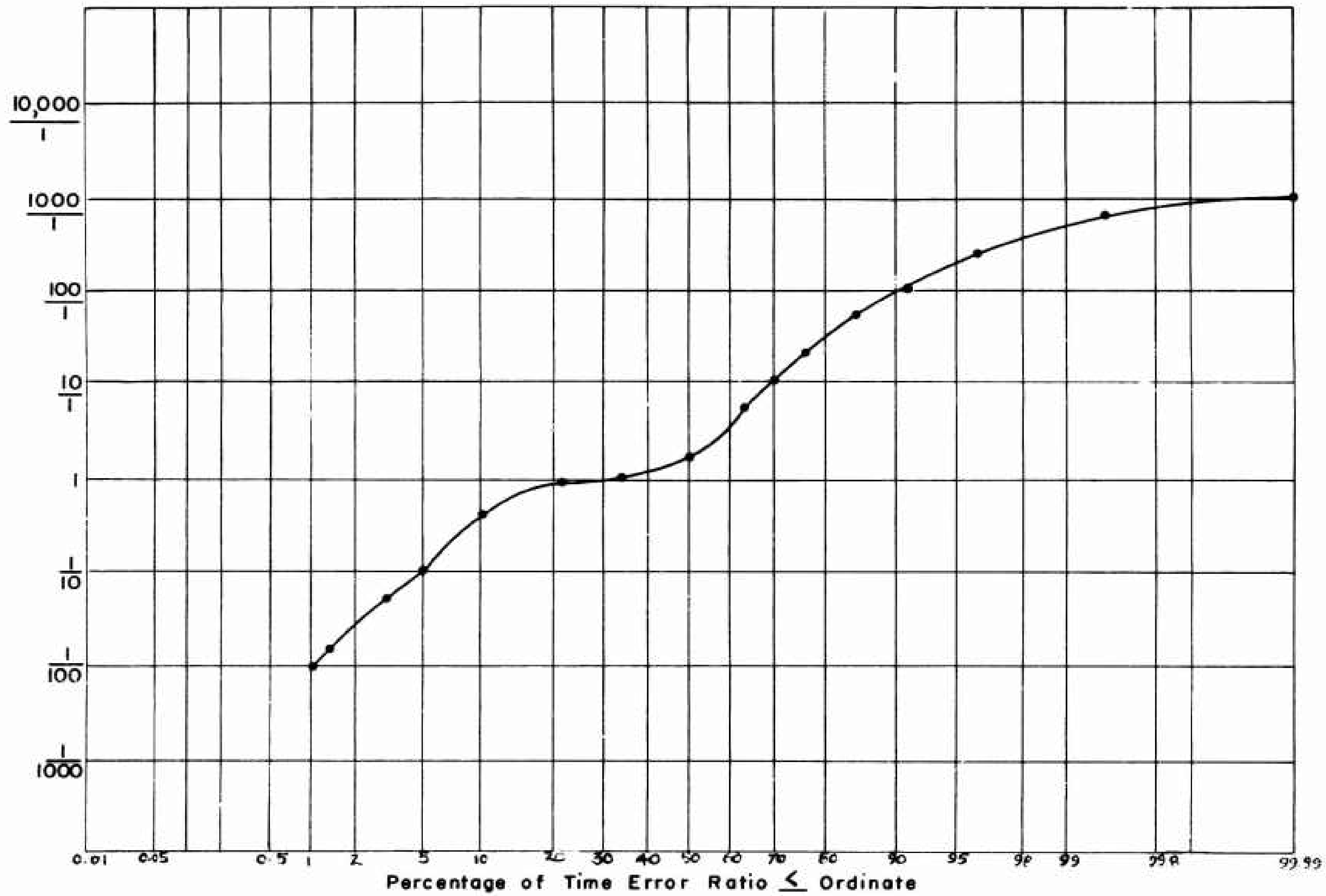

Figure 22. Distribution of Ratio of AD-FALC to PDC

SECTION IV

CONCLUSIONS

1. AMI

a. The evaluation of the AD-FALC-AMI in terms of 2400 b/s modem performance has indicated the following:

(1) The AD-FALC-AMI combination provided worse performance than the conventional FM system.

(2) The AD-FALC-AMI did not offer any improvement over the AD-FALC system.

(3) The AMI should not be evaluated, however, strictly in terms of modem performance because its basic function is to minimize channel noise, by improving above-threshold performance at the expense of below-threshold performance.

(4) This evaluation does not show any valid conclusions regarding the effect of AMI on the conventional FM system simply because these tests involved AMI adaptation to the AD-FALC system. The resulting unavoidable imposition of AMI on the conventional FM system does not necessarily imply an optimum adaptation to it.

b. The evaluation of the AD-FALC-AMI in terms of voice channel noise performance has indicated the following:

(1) The conventional FM system (without AMI) provided better voice channel noise performance than the AD-FALC-AMI system (Figure 6).

(2) The AD-FALC system (without AMI) provided better voice channel noise performance than the AD-FALC-AMI (Figure 7).

(3) The conventional FM system (without AMI) provided better voice channel noise performance than the conventional FM with AMI (Figure 8). However, for reasons cited previously, this should not be construed as a valid conclusion regarding the effect of AMI on the conventional FM systems.

(4) Despite the AMI activity indicated by Figure 10, there is no evidence that the AMI aided the AD-FALC system either in terms of voice channel noise performance or in terms of modem performance.

2. AD-FALC

Although the data indicates that the quadruple space-frequency diversity boresight system performed better than the quadruple AD system, this should not be construed as valid for the AD system. The AD system is readily capable of expansion to 12 or 16 orders of angle-space diversity by using bi-polarized AD feedhorns on both space-diversity receive antennas. Under such conditions, and with the AD system properly implemented, it should easily outperform the boresight system both in terms of modem performance and voice channel noise performance. During "normal" propagation conditions, this AD system should, at worst, perform as well as the boresight one and during the "abnormal" propagation conditions when the boresight system is most vulnerable, it should greatly outperform it. This is indicated in the upper curve of Figure 9.

However, the proper implementation of such an AD system would be difficult. As was evident during all phases of AD testing at DYE 4/5, the path length associated with each AD feedhorn must be equalized with regard to differential propagation time. The differential delay between the AD feedhorns was compensated for by inserting variable delay lines into all but the longest path. The amount of delay inserted into each path was manually adjusted on an hourly basis by a trial and error procedure. However only gross delay could be adjusted, it was valid only during a portion of each adjustment interval, and the AD system performance was highly sensitive to such adjustments. Unfortunately no method has been established for performing this adjustment automatically and on an adaptive basis. Therefore the normally accepted method of angle diversity is not recommended for DYE 4/5.

Instead, it would be better to implement AD only for the purpose of selecting the matched pair of space-diversity feedhorns with the best signal and to combine the outputs of these two bi-polarized feedhorns in a quadruple space-frequency diversity basis. This method precludes high order diversity on a short-term basis. This is acceptable because, regardless of the propagation mode, a high signal appears to be available either on the boresight horns or on the off-set horns at all times so more diversity is not required. What is required is to select the proper horns from which to operate. Twelve-order angle diversity at all times relative to this recommended type of angle-space diversity will provide much better modem performance but it will not provide any significant voice channel noise improvement. It must be recognized, therefore, that this configuration would help the DYE 4/5 performance only during those times when the "abnormal" propagation conditions persist.

3. PATH INTERMODULATION AND NOISE

Another conclusion is that much of both the long and short term poor performance was due to noise in the system and not to the lack of received signal. In addition to thermal noise, there were undoubtedly two other basic sources of noise: equipment noise and path intermodulation noise.

a. Equipment Noise

This appeared to have emanated from several sources: the co-located 50 KW power amplifiers, the low noise receiver parametric amplifiers, and the post-detection combiners.

(1) Transmitter Noise

During all tests, the passband of the receivers was displayed on a spectrum analyzer. Noise was frequently observed and attributed to the co-located transmitters. Two methods were used to successfully eliminate the noise at different times: retuning the 2nd and 3rd cavities of the 50 KW klystrons and reducing the high power output to 15 or 20 KW. At other times no successful method was found. How the co-located transmitter was able to inject power into the receivers is not consistent and is not completely understood.

Since it occurred numerous times during testing, this noise condition obviously persists for a significant portion of the year. It was observed and remedied only because a spectrum analyzer was used. Unfortunately the station operators have no equipment for observing such occurrences and, therefore, are in no position to remedy it. It undoubtedly contributes to the poor performance of the link.

(2) Parametric Amplifier

These devices are used on all receivers at DYE 4/5. Approximately a dozen different adjustments are required to properly tune them. During testing, the performance of these units was checked at least several times a day, sometimes hourly, and more often than not the units required re-adjustment. Improper operation ranged from gain instability, to change in noise figure, to oscillations, all of which result in noise in the baseband or level instability, which, in turn, degrade performance of the system.

That this condition persists for a significant portion of the year is also without qestion. Again, the station operators have no way of monitoring the performance of the units. Improper operation is observed and remedied only during schedule maintenance periods once a week.

(3) Baseband Combiner

Although there are several ways in which improper operation of this unit can occur, the basic one was due to overloading the voice channels. It was observed that the second harmonic of information inserted in the voice channels was quite high. The spectrum location of the second harmonic was in the out-of-band portion where FM is detected and used for controlling the combining action. The result is that false information was used as a basis for performing the operation.

b. Path Noise

The presence of path intermodulation noise was observed in several different ways: the level instability of a tone inserted into a voice channel, the correlation of modem errors to the variations in the tone level, and modem performance much poorer than that dictated by Gaussian noise and Rayleigh signal.

This noise was also observed on all beams including the angle-diversity ones. Special tests were conducted where dual space-diversity operation was achieved at the various vertical elevations of the angle-diversity beams of both receive antennas. These tests indicated that the boresight beams generally had much more path intermodulation noise than the off-set beams. There were, in fact, instances where the off-set beams, with far less signal power, gave far better modem performance than the boresight system. This may have been because each boresight beam receives signals from two sources: the first directly from the "common volume," the second reflected from the ocean. The more elevated angle-diversity beams receive signals from only one source: the "common volume."

SECTION V

RECOMMENDATIONS

The DYE 4/5 troposcatter communications circuit performs submarginally at best. Even under high received signal level conditions, its performance may be poor for reasons which have been conveniently attributed to path intermodulation noise. Under insufficient received signal level conditions, the cause of the outage is of course apparent.

To minimize the outage time due to lack of signal on the boresight beams, it is recommended that angle diversity be employed whenever this occurs.

Even with the incorporation of angle diversity to improve the long term performance, the short term performance will still be generally poor due to equipment problems and path intermodulation noise. The equipment problems can be minimized by replacing the complex and unstable units, preventing transmitter emissions from interfering with co-located receivers, preventing baseband and voice channel overload conditions, etc. Accordingly, the parametric amplifiers should be replaced by fixed-tuned transistorized pre-amplifiers which have 3-4 db noise figures and instantaneous bandwidths from 755 to 985 MHz. Since angle diversity would presumably involve a total of at least 12 receivers per station, it is recommended that the present type of baseband combiner be replaced by a pre-detection combiner such as the FALC or the Raytheon PDC. Cross talk and NPR can be controlled by the use of limiters employed in such a way that any voice channel overload would affect only the channel that is overloaded. The introduction of transmitter power into the co-located receivers is a very serious problem. How the interferring power enters the receivers is not precisely or positively known. The AN/FRC-39 transmitter manufacturer should be brought on-site for the purpose of determining this.

Only after the equipment problems are resolved will it be feasible to attack the path intermodulation noise problem. Since dubious improvement was achieved by the AMI device, and since the noise which was attributed to path intermodulation appears to be independent relative to the various beams, the solution may be to develop a diversity combiner that combines not only in proportion to the quantity but also the quality of signal in the diversity branches.

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APPENDIX

TEST DATA (12 MARCH 68 — 26 MARCH 68)

LEGEND

Type A tests - AMI on, both systems

Type N tests - AMI off, both systems

Pe = probability of bit errors (measured)

$$= \frac{\text{total bit errors per 5 minute interval}}{\text{total bits transmitted per 5 minute interval}}$$

Received carrier level

(1) Specified in -dbm (measured).

(2) Horn 1 refers to the boresight horns of both receive antennas. For the conventional system, it refers to 4 horns, 2 in the vertical polarization and 2 in the horizontal polarization. For the angle-diversity system, there is only one horn, set in the vertical polarization.

(3) Horn 4 refers to the angle-diversity horn which is positioned below Horn 1.

(4) Horn 8 refers to the angle-diversity horn which is positioned above Horn 1.

(5) Horn 10 refers to the angle-diversity horn which is positioned below Horn 4.

12 March 1968

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
11	A	78	81	84	96	$3X10^{-4}$	$1.5X10^{-5}$
12	N	78	81	84	95	$5X10^{-4}$	0
13	A	79	80	84	96	$2.5X10^{-5}$	$7.7X10^{-6}$
14	N	77	80	83	95	$2.6X10^{-4}$	$9X10^{-6}$
15	A	77	80	85	96	$6.2X10^{-5}$	$4.6X10^{-6}$
16	N	77	81	84	95	$5.4X10^{-4}$	$4.6X10^{-6}$
17	A	77	81	84	96	$3X10^{-4}$	$3.7X10^{-6}$
18	N	76	81	84	96	$3X10^{-4}$	$2.3X10^{-6}$
19	A	77	79	84	95	$3X10^{-5}$	$7.7X10^{-4}$
20	N	77	81	84	95	$1.4X10^{-4}$	$2.6X10^{-4}$
21	A	79	81	84	96	$1.2X10^{-4}$	$1.4X10^{-5}$
22	N	79	79	84	95	$2.3X10^{-4}$	$1X10^{-4}$

*Notation indicated in Section II, Paragraph 1. applies: i.e., TEST TYPE A is with AMI on and TEST TYPE N is with AMI off. Also, AMI is controlled by the AD-FALC System.

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
10	A	100	86	83	92	$3.4X10^{-4}$	$2.3X10^{-3}$
11	N	99	85	83	91	$5.6X10^{-4}$	$2.2X10^{-3}$
12	A	99	85	83	93	$2.5X10^{-3}$	$4.2X10^{-3}$
13	N	99	85	83	93	$3.2X10^{-4}$	$5.1X10^{-3}$
14		99	85	84	93	VOID	VOID
15	N	99	85	83	92	$5.5X10^{-5}$	$2.2X10^{-3}$
16	A	99	87	83	93	$2.4X10^{-4}$	$3X10^{-3}$
17	N	101	84	82	92	$5.8X10^{-5}$	$1.6X10^{-3}$
18	A	100	84	83	92	$3.7X10^{-4}$	$5.7X10^{-3}$
19	N	101	85	83	93	$1.6X10^{-4}$	$4.3X10^{-3}$
20	A	101	84	82	94	$3X10^{-4}$	$1.2X10^{-3}$
21	N	102	85	83	93	$7X10^{-4}$	$1.7X10^{-3}$
22	A	101	84	83	93	$6.6X10^{-4}$	$1.5X10^{-3}$
23	N	102	83	83	93	$3.4X10^{-4}$	$2.4X10^{-3}$
24	A	103	85	83	93	$6.0X10^{-4}$	$2.4X10^{-3}$
25	N	100	82	82	92	$5.1X10^{-4}$	$1.8X10^{-3}$
26	A	101	83	83	93	$5.9X10^{-4}$	$2.3X10^{-3}$

*Notation indicated in Section II, Paragraph 1 applies: i.e., TEST TYPE A is with AMI on and TEST TYPE N is with AMI off. Also, AMI is controlled by the AD-FALC System.

14 March 1968

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
1	N	82	88	85	97	$1X10^{-4}$	$2.8X10^{-5}$
2	A	82	87	85	96	$2.7X10^{-4}$	$1.4X10^{-5}$
3	N	81	87	84	97	$8X10^{-5}$	$3X10^{-6}$
4	A	83	87	86	97	$1X10^{-3}$	$4X10^{-6}$
5	N	82	87	86	98	$1.3X10^{-4}$	$1.4X10^{-6}$
6	A	81	89	85	98	$7X10^{-5}$	$3X10^{-5}$
7	N	81	87	84	97	$4X10^{-4}$	$1X10^{-4}$
8	A	81	88	85	95	$1.7X10^{-5}$	$2X10^{-5}$
9	N	82	87	84	97	$6.6X10^{-4}$	$4.5X10^{-5}$
10	A	82	87	85	98	$2X10^{-3}$	$2.5X10^{-4}$
11	N	82	87	84	95	$3.2X10^{-4}$	$1X10^{-4}$
12	A	82	85	86	95	$2.3X10^{-4}$	$1.4X10^{-6}$
13	N	83	86	86	97	$3.7X10^{-4}$	$1.7X10^{-4}$
14	A	82	86	87	97	$1X10^{-4}$	0
15	N	83	87	86	96	$6X10^{-4}$	0
16	A	82	88	84	97	$3.5X10^{-5}$	$1.4X10^{-6}$
17	N	82	87	85	95	$3.5X10^{-4}$	$2.3X10^{-4}$
18	A	84	87	85	96	$3X10^{-4}$	$1.4X10^{-6}$
19	N	83	87	87	96	$3.7X10^{-4}$	$2.8X10^{-6}$
20	A	82	86	85	96	$1.5X10^{-3}$	$7X10^{-6}$

14 March 1968 (Cont'd)

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
21	N	82	87	86	96	$7.8X10^{-5}$	$5.5X10^{-6}$
22	A	83	88	85	96	$4.2X10^{-4}$	$7X10^{-6}$
23	N	84	86	84	96	$7.7X10^{-5}$	$2.2X10^{-5}$
24	A	84	87	85	97	$3X10^{-4}$	$7.4X10^{-4}$
25	N	85	88	86	95	$2X10^{-4}$	$2.2X10^{-4}$
26	A	84	85	88	96	$5X10^{-5}$	$6X10^{-4}$
27	N	84	87	85	97	$4X10^{-4}$	$3.6X10^{-4}$
28	A	84	87	85	95	$1.7X10^{-4}$	$6.8X10^{-4}$
29	N	87	86	85	96	$1.5X10^{-4}$	$3X10^{-4}$
30	A	85	85	85	95	$6X10^{-5}$	$5.5X10^{-5}$

*Notation indicated in Section II, Paragraph 1 applies: i.e., TEST TYPE A is with AMI on and TEST TYPE N is with AMI off. Also, AMI is controlled by the AD-FALC System.

18 March 1968

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
1	A	82	82	82	93	$3.6X10^{-5}$	$1.8X10^{-4}$
2	N	84	82	82	93	$3X10^{-4}$	$2.1X10^{-4}$
3	A	87	81	82	93	$7.4X10^{-5}$	$2X10^{-4}$
4	N	85	81	82	94	$1.2X10^{-4}$	$6.3X10^{-5}$
5	A	84	82	81	93	$1.4X10^{-5}$	$1X10^{-4}$
6	N	84	81	82	94	0	$1.3X10^{-4}$
7	A	83	83	81	94	$3.6X10^{-5}$	$3.6X10^{-5}$
8	N	83	83	82	94	$1.0X10^{-3}$	$2.5X10^{-5}$
9	A	85	83	83	94	$1.4X10^{-5}$	$3.3X10^{-4}$
10	N	85	84	82	95	$2X10^{-5}$	$1.1X10^{-5}$
11	A	85	84	82	95	$4.6X10^{-5}$	0
12	N	85	84	82	94	$3.6X10^{-5}$	0
13	A	87	84	82	94	$1.2X10^{-5}$	$8.3X10^{-6}$
14	N	87	85	84	96	$2.4X10^{-5}$	$1.4X10^{-6}$
15	A	86	86	83	95	$4.2X10^{-5}$	0
16	N	87	86	83	95	$1.4X10^{-4}$	$1.4X10^{-6}$
17	A	87	84	84	94	$7X10^{-6}$	$1.4X10^{-6}$
18	N	85	83	84	97	$4X10^{-5}$	$1.4X10^{-6}$
19	A	85	85	84	96	0	0
20	N	84	85	84	95	$7.5X10^{-5}$	$1.4X10^{-6}$
21	A	84	84	84	95	$1.5X10^{-5}$	0
22	N	85	84	83	94	$2.1X10^{-5}$	$1.5X10^{-5}$
23	A	84	86	83	97	$1.8X10^{-5}$	$2X10^{-5}$
24	N	83	85	83	94	$5.5X10^{-6}$	$1.4X10^{-6}$
25	A	84	84	83	94	$6.7X10^{-5}$	$3.8X10^{-5}$

18 March 1968 (Cont'd)

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
26	N	83	84	83	94	2.5×10^{-5}	1.2×10^{-5}
27	A	84	84	84	93	2.8×10^{-5}	1.4×10^{-6}
28	N	84	84	84	94	9.3×10^{-4}	2.4×10^{-5}
29	A	83	83	83	95	2.8×10^{-5}	7×10^{-6}
30	N	83	84	82	94	5.3×10^{-5}	0
31	A	83	84	84	95	5.6×10^{-6}	0
32	N	84	84	84	94	5.7×10^{-5}	3.8×10^{-5}
33	A	84	84	84	96	1.1×10^{-5}	0
34	N	83	84	83	96	2×10^{-5}	5.6×10^{-6}
35	A	83	84	83	95	4.4×10^{-4}	4×10^{-5}
36	N	84	84	84	95	5.7×10^{-5}	4.6×10^{-5}
37	A	84	84	32	94	5×10^{-5}	2.5×10^{-5}
38	N	83	84	84	94	4.8×10^{-4}	0
39	A	85	84	83	95	2.8×10^{-5}	3.5×10^{-5}
40	N	82	84	84	96	5.6×10^{-4}	4.3×10^{-4}
41	A	83	84	82	96	6.8×10^{-4}	7.5×10^{-4}
42	N	83	86	83	94	2×10^{-5}	1.8×10^{-4}
43	A	84	83	83	95	4.6×10^{-5}	2.7×10^{-4}
44	N	82	84	82	95	2.2×10^{-4}	1.9×10^{-6}
45	A	84	84	83	95	1.4×10^{-5}	7.2×10^{-5}
46	N	84	84	82	95	3.4×10^{-4}	2.5×10^{-5}
47	A	83	84	83	96	1.1×10^{-5}	8.9×10^{-5}
48	N	84	83	83	94	1×10^{-4}	8.7×10^{-5}
49	A	84	82	84	95	7×10^{-5}	2.8×10^{-6}
50	N	83	83	82	94	3×10^{-4}	8×10^{-5}

18 March (Cont'd)

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
51	A	84	83	83	95	$3X10^{-4}$	$8.3X10^{-6}$
52	N	83	82	82	95	$1.4X10^{-6}$	$5X10^{-4}$
53	A	82	85	84	98	$1.1X10^{-4}$	$7.7X10^{-4}$
54	N	85	82	84	97	$1.2X10^{-5}$	$1.4X10^{-6}$
55	A	84	84	84	96	$7.7X10^{-5}$	$5X10^{-5}$
56	N	83	83	83	97	$5.6X10^{-5}$	$5.7X10^{-5}$
57	A	84	83	84	97	0	$5.6X10^{-6}$
58	N	83	84	85	97	$2X10^{-4}$	$1.2X10^{-4}$
59	A	83	83	82	96	$1.2X10^{-5}$	$2.8X10^{-6}$
60	N	82	82	83	96	0	$5.6X10^{-6}$
61	A	87	82	82	95	$1.4X10^{-5}$	$2.8X10^{-6}$
62	N	83	83	83	95	$2.2X10^{-5}$	$2.1X10^{-5}$
63	A	85	84	84	97	$3.6X10^{-5}$	$8X10^{-5}$

*Notation indicated in Section II, Paragraph 1 applies: i.e., TEST TYPE A is with AMI on and TEST TYPE N is with AMI off. Also, AMI is controlled by the AD-FALC System.

20 March 1968

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
1a	A	84	83	83	94	4.2×10^{-6}	2.8×10^{-6}
1b	N	84	83	83	94	1.8×10^{-4}	2.7×10^{-4}
2a	A	86	84	84	94	8.2×10^{-4}	0
2b	N	86	84	84	94	3.6×10^{-5}	0
3a	A	84	84	84	95	6.5×10^{-5}	8.1×10^{-5}
3b	N	84	84	84	95	4.5×10^{-4}	6×10^{-4}
4a	A	83	83	84	94	2.5×10^{-5}	1.8×10^{-5}
4b	N	83	83	84	94	5.3×10^{-5}	1.4×10^{-6}
5a	A	85	83	84	95	9.7×10^{-5}	9.7×10^{-6}
5b	N	85	83	84	95	5.5×10^{-4}	2.9×10^{-4}
6a	A	85	83	84	95	3×10^{-5}	1.4×10^{-6}
6b	N	85	83	84	95	9.7×10^{-5}	2.8×10^{-6}
7a	A	84	83	84	94	4.6×10^{-5}	4.2×10^{-6}
7b	N	84	83	84	94	3.2×10^{-5}	7×10^{-6}
8a	A	84	82	83	95	5.1×10^{-4}	1.4×10^{-5}
8b	N	84	82	83	95	3.6×10^{-4}	4×10^{-5}
9a	A	84	83	83	96	1.3×10^{-4}	1.8×10^{-5}
9b	N	84	83	83	96	8×10^{-5}	5.5×10^{-6}
10a	A	84	84	83	95	8×10^{-5}	1.5×10^{-5}

20 March 1968 (Cont'd)

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
10b	N	84	84	83	95	$3X10^{-6}$	$1.3X10^{-4}$
11a	A	84	8[illegible]	84	95	0	$7X10^{-6}$
11b	N	84	83	84	95	$2.8X10^{-6}$	$4.2X10^{-6}$
12a	A	83	83	83	94	0	$5.5X10^{-6}$
12b	N	83	83	83	94	$8.3X10^{-6}$	$4X10^{-5}$
16a	A	83	83	83	95	$2.5X10^{-4}$	$6.8X10^{-5}$
16b	N	83	83	83	95	$9.7X10^{-6}$	$5X10^{-5}$
17a	A	85	82	84	94	$9.7X10^{-6}$	$3X10^{-5}$
17b	N	85	82	84	94	2.[illegible]$X10^{-4}$	$4X10^{-4}$
18a	A	83	82	82	93	3.[illegible]$X10^{-5}$	$2X10^{-5}$
18b	N	83	82	82	93	0	$9.7X10^{-6}$
19a	A	85	83	84	94	3.[illegible]$X10^{-5}$	$7X10^{-6}$
19b	N	85	83	84	94	3.[illegible]$X10^{-5}$	$7X10^{-6}$
20a	A	85	83	83	95	1.[illegible]$X10^{-6}$	$6X10^{-4}$
20b	N	85	83	83	95	7.[illegible]$X10^{-5}$	$3.3X10^{-4}$

*Notation indicated in Section II, Paragraph 1 applies: i.e., TEST TYPE A is with AMI on and TEST TYPE N is with AMI off. Also, AMI is controlled by the ADFALC System.

26 March 1968

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
1a	A	79	87	86	95	$3.7X10^{-3}$	$1.5X10^{-4}$
1b	N	79	87	86	95	$5.3X10^{-5}$	$1.5X10^{-4}$
2a	A	78	85	85	95	$6.5X10^{-3}$	$1.7X10^{-4}$
2b	N	78	85	85	95	$1.1X10^{-3}$	$1.3X10^{-5}$
3a	A	78	87	86	96	$1X10^{-4}$	0
3b	N	78	87	86	96	$4.2X10^{-4}$	$8.9X10^{-5}$
4a	A	80	87	87	94	$9.7X10^{-5}$	$8.4X10^{-6}$
4b	N	80	87	87	94	$4.2X10^{-4}$	$5.2X10^{-5}$
5a	A	78	87	87	92	$2.3X10^{-3}$	$7X10^{-5}$
5b	N	78	87	87	92	$3X10^{-4}$	$3.3X10^{-5}$
6a	A	80	87	86	92	$6.7X10^{-4}$	$6.7X10^{-4}$
6b	N	80	87	86	92	$7.3X10^{-4}$	$7.3X10^{-4}$
7a	A	79	87	86	92	$4.1X10^{-3}$	$7.8X10^{-5}$
7b	N	79	87	86	92	$7.8X10^{-5}$	$2.5X10^{-5}$
8a	A	79	87	86	92	$4.3X10^{-5}$	$2.8X10^{-6}$
8b	N	79	87	86	92	$4.7X10^{-4}$	0
9a	A	80	87	86	92	$2.4X10^{-3}$	$1X10^{-4}$
9b	N	80	87	86	92	$1.4X10^{-6}$	0
10a	A	80	86	86	92	$1.7X10^{-3}$	$4.6X10^{-5}$

26 March 1968 (Cont'd)

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
10b	N	80	86	86	92	$2.2X10^{-4}$	$1.4X10^{-6}$
11a	A	79	86	86	92	$1.1X10^{-4}$	$2X10^{-4}$
11b	N	79	86	86	92	$3X10^{-4}$	$1.4X10^{-6}$
12a	A	81	87	86	91	$5.6X10^{-3}$	$1.8X10^{-4}$
12b	N	81	87	86	91	$8.1X10^{-5}$	$2.8X10^{-6}$
13a	A	79	87	87	92	$6.3X10^{-4}$	$1.4X10^{-5}$
13b	N	79	87	87	92	$7.3X10^{-4}$	0
14a	A	81	87	87	92	$3.8X10^{-4}$	0
14b	N	81	87	87	92	$4.2X10^{-5}$	0
15a	A	80	87	85	92	$3.4X10^{-4}$	0
15b	N	80	87	85	92	$9.3X10^{-5}$	0
16a	A	81	87	85	93	$2.8X10^{-6}$	0
16b	N	81	87	85	93	$5.7X10^{-5}$	0
17a	A	81	88	86	92	$3.6X10^{-5}$	$1.4X10^{-6}$
17b	N	81	88	86	92	$4.7X10^{-4}$	$7.4X10^{-5}$
18a	A	78	88	85	92	$7X10^{-4}$	0
18b	N	78	88	85	92	$1X10^{-5}$	0
19a	A	76	87	84	93	$6.5X10^{-4}$	$2X10^{-5}$
19b	N	76	87	84	93	$4.4X10^{-4}$	$1.4X10^{-6}$
20a	A	76	87	84	93	$6.5X10^{-4}$	$2X10^{-5}$

26 March 1968 (Cont'd)

Run #	Test Type	Median Carrier Level (-dbm)				Pe	
		Horn 1	Horn 4	Horn 8	Horn 10	Test System	*Conventional System
20b	N	76	87	84	93	$4.4X10^{-4}$	$1.4X10^{-6}$
21a	A	79	86	85	92	$3.3X10^{-3}$	$1.4X10^{-4}$
21b	N	79	86	85	92	$9X10^{-5}$	$3X10^{-6}$
22a	A	79	86	84	92	$4X10^{-5}$	0
22b	N	79	86	84	92	$3X10^{-5}$	0
23a	A	79	87	85	92	$1.3X10^{-4}$	0
23b	N	79	87	85	92	$2.8X10^{-6}$	0
24a	A	79	87	85	92	$1.5X10^{-4}$	0
24b	N	79	87	85	92	$7.7X10^{-4}$	0
25a	A	81	87	84	92	$1.7X10^{-4}$	$1.2X10^{-4}$
25b	N	81	87	84	92	$4.6X10^{-5}$	$1.4X10^{-6}$
26a	A	82	87	84	91	$3.6X10^{-3}$	$4.3X10^{-5}$
26b	N	82	87	84	91	$2.5X10^{-5}$	$1.4X10^{-4}$
27a	A	82	87	85	92	$8.2X10^{-4}$	$2.2X10^{-4}$
27b	N	82	87	85	92	$2.8X10^{-6}$	$1.4X10^{-4}$
28a	A	83	86	84	92	$2X10^{-5}$	$1.7X10^{-5}$
28b	N	83	86	84	92	$2.8X10^{-5}$	$4.2X10^{-6}$
29a	A	81	74	73	91	$3.5X10^{-5}$	$7X10^{-4}$
29b	N	81	74	73	91	$1.6X10^{-3}$	$5.8X10^{-4}$

*Notation indicated in Section II, Paragraph 1 applies: i.e., TEST TYPE A is with AMI on and TEST TYPE N is with AMI off. Also, AMI is controlled by the AD-FALC System.

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13. ABSTRACT

During the period of November 1967 to June 1968, tests were conducted on the DYE 4/5 Troposcatter Communications Link by Bell Telephone Laboratories (BTL), Communications & Systems Inc. (C&S), and Raytheon Company. The purpose of these tests was to evaluate techniques such as angle diversity, pre-detection diversity combining, and adaptive FM as possible means of improving the operational performance of that link. BTL's techniques consisted of angle diversity and a pre-detection combiner called "FALC"; C&S's technique was that of adaptive FM; and Raytheon's technique was a predetection combiner called "PDC." This report describes the joint tests and the evaluation which was performed by RADC during March and April 1968 when the above-mentioned techniques were integrated into a single entity and compared to the normal-operational FM/FDM system. Test results indicated that although both the test system and the normal-operational FM/FDM system performed rather poorly, the better performance was achieved most of the time by the operational FM/FDM system. There were also instances when propagation outage conditions occurred in the operational FM/FDM system but not in the test system. During such periods, the improved performance of the test system was attributed to its angle diversity aspects rather than to its pre-detection combining or adaptive FM aspects. It is also shown that the adaptive FM technique degrades the test system when the system also includes the FALC pre-detection combiner. Recommendations include the use of angle diversity mainly to reduce propagation outages which would be experienced if the system operation was limited to the boresight beams.

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Diversity Reception						
Troposphere						
Frequency Modulation						
Propagation						
Scattering						

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